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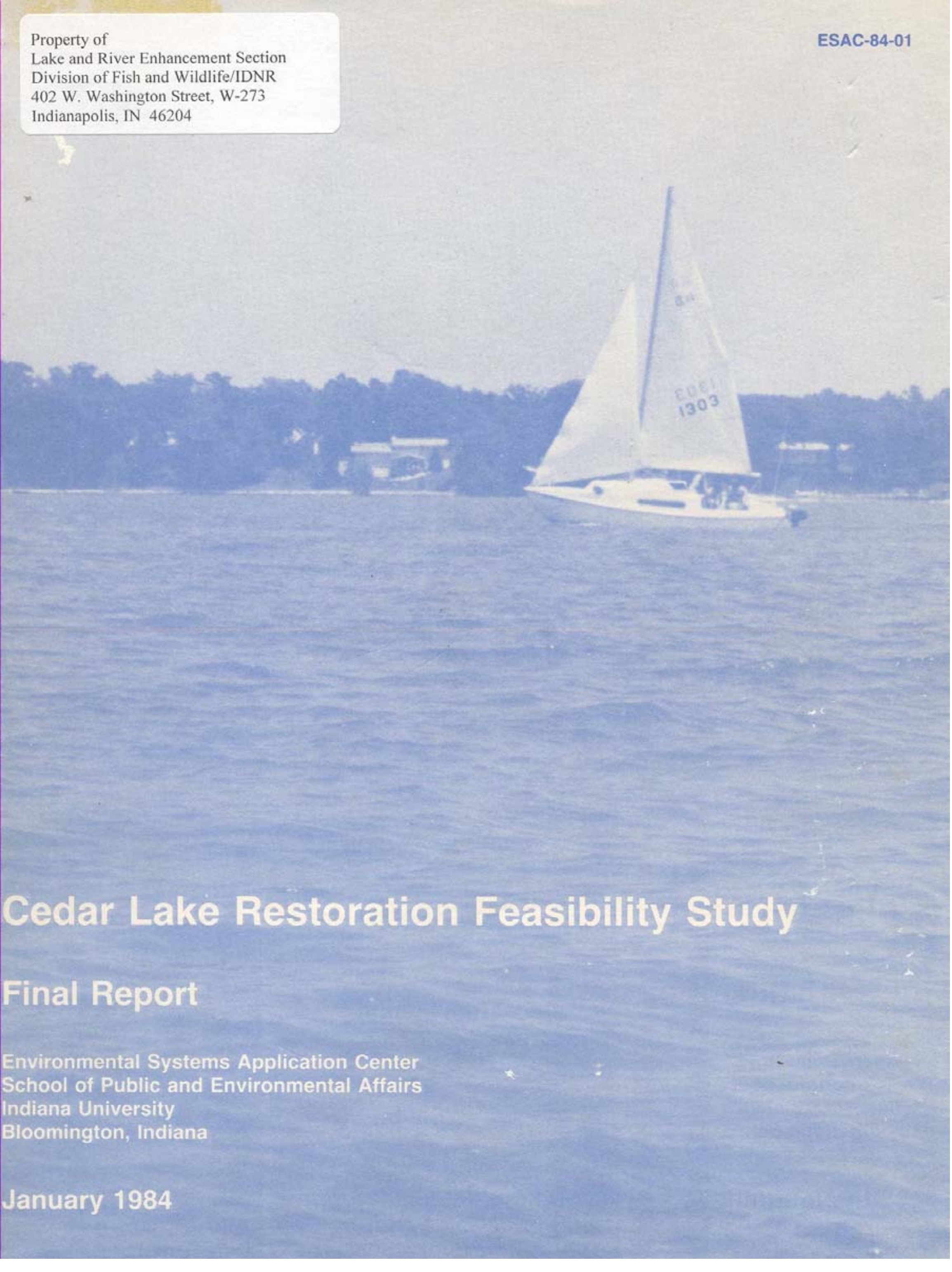

Cedar Lake Restoration Feasibility Study

Final Report

Environmental Systems Application Center
School of Public and Environmental Affairs
Indiana University
Bloomington, Indiana

January 1984

ESAC-84-01

CEDAR LAKE RESTORATION FEASIBITITY STUDY

- FINAL REPORT -

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DISCLAIMER

This project has been financed with State of Indiana funds administered by the Indiana Department of Natural Resources and Federal funds administered by the U.S. Environmental Protection Agency and Ball State University. The contents do not necessarily reflect the views and policies of the Indiana Department of Natural Resources, U.S. Environmental Protection Agency, or Ball State University, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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PREFACE

Due to deteriorating water quality conditions in Cedar Lake and a request by local citizens for assistance, the 1978 Indiana State Legislature appropriated funds to determine the feasibility of restoring Cedar Lake. The Indiana Department of Natural Resources (DNR) was delegated the responsibility for administering the funds and selecting a consultant to conduct the study. The proposal submitted by the Environmental Systems Application Center (ESAC) at Indiana University's School of Public and Environmental Affairs (SPEA) was finally selected and a formal contract was entered into on October 23, 1978. Work was initiated on January 1, 1979.

The eleven month study, referred to as the Cedar Lake Restoration Feasibility Study - Part One, was completed in November, 1979 and a final report was submitted to the Indiana Department of Natural Resources. Following a review by the DNR and publication of the Final Regulations for the Clean Lakes Program (section 314 of the Clean Water Act) on February 5, 1980, several additional research areas, as required by the new regulations, were identified as being necessary before a Phase 2 implementation program for Cedar Lake could be approved. A proposal to complete these requirements under Phase 1 diagnostic/feasibility study grant was prepared and submitted to the U.S. Environmental Protection Agency through Dr. Byron Torke, Indiana's Clean Lakes Coordinator. This grant was approved on April 1, 1981. The work under this grant, known as Part Two, was fully initiated in September, 1981.

This report is the final report of the Cedar Lake Restoration Feasibility Study and includes both Part One and Part Two of the study. This report has been reviewed and approved by the Region V Office of the U.S. Environmental Protection Agency.

ACKNOWLEDGEMENTS

We would like to thank Professor Donald R. Whitehead, Mark Sheehan, and the rest of their laboratory staff for their assistance in sediment core acquisition and pollen analysis, and Professor Peter M. Vitousek and his laboratory staff for the analysis of certain water and sediment samples on the Technicon Autoanalyzer II. Joe Domaglaski provided gas chromatography analyses and Professor Ronald A. Hites and his laboratory staff conducted the GC/MS analyses of sediment samples. The metals analyses on the atomic adsorption spectrophotometer were conducted in cooperation with Joseph G. Hailer and the Indiana Geological Survey. Mark Flora and John Dolezal both aided in the acquisition of existing data concerning Cedar Lake. Bob Robertson, District 1 Fish Management Biologist with the Indiana Department of Natural Resources, directed the 1979 Fisheries survey. Jack Kratzmeyer, U.S. Environmental Protection Agency, Region V, operated the Septic Leachate Detector and provided expert analysis of those results.

We gratefully acknowledge the valuable comments and critical analysis of our work provided by Professor D.G. Frey, Indiana University and Professor Thomas L. Theis, University of Notre Dame. Drs. Robert H. Kadlec, Joseph Shapiro, and William E. Sloey provided invaluble analysis of Part One results and suggested important additional studies for Part Two under EPA's Lake Assistance Service Program (LASP).

The follwoing individuals with the Indiana Department of Natural Resources provided valuable assistance and information to this project: William J. Andrews, G. Douglas Clark, Ed Hartke, Jim Hebenstreit, Bill Steen, and Dick Wawrzyniak. Earl A. Bohner, Oral H. Hert, and John Winters of the Indiana State Board of Health reviewed the draft report and provided helpful comments. Wayne Gorski, Bob Tolpa, Jerry Phillips, Dale Leucht, Richard Parkin and Donald Josif of the U.S. Environmental Protection Agency also provided us with valuable assistance. Dr. Byron G. Torke, Indiana Clean Lakes Coordinator, provided essential administrative services to this report.

We wish to thank Bob and Ted Gross of the Pinecrest Marina, Jack LeMay, Charles Thornburg, Joe Gornick, and many other residents of Cedar Lake for their assistance in helping us conduct a thorough lake survey.

Graphics for the final report were prepared with the assistance of John S. Hart and Keith Bobay. Joan Wiggins and Pam Duitsman prepared the final manuscript, which was edited by William W. Jones.

SUMMARY

1. Cedar Lake is a 316 hectare (781 acre) "ice block" lake located in Lake County in northwestern Indiana. The lake is shallow with a maximum depth of only 4.9 meters (16 feet) and a mean depth of 2.7 meters (8.8 feet). Because Cedar Lake is situated on a topographic divide, its drainage area is quite small. This provides for limited runoff and a somewhat slow hydraulic flushing rate.

2. Cedar Lake has been a popular resort area since the early 1900's. This has resulted in a heavily developed shoreline, with many dwellings on undersized lots. Until 1977, all residences were served by individual domestic septic systems. The combination of small lot size, poorly drained soils and a seasonally high water table can contribute to septic system failures, allowing inadequately treated wastewater from septic systems to enter Cedar Lake. Inadequately treated wastewater, from septic systems and from a small wastewater treatment plant, has been blamed for contributing large loadings of nutrients to Cedar Lake.

3. There is a high degree of turbidity present in Cedar Lake's waters caused by the resuspension of flocculent sediments due to winds, motor boats, and fish.

4. Cedar Lake has a meromictic circulatory pattern - no permanent stratification was observed. Temporary stratification was observed during periods of calm winds. Dissolved oxygen concentrations were low in the deepest waters at the end of winter and during calm wind conditions in the summer. This suggests that anoxic conditions may be present in the sediments.

5. Phosphorus and nitrogen data suggest that Cedar Lake is nitrogen limited. Soluble reactive (available) phosphorus concentrations increased in the lake throughout the summer of 1979 until August, when they represent more than 50% of total lake phosphorus. Nitrate levels decrease through the spring and remain near zero during the summer.

6. Cedar Lake suffers from seasonally high algal blooms, dominated by blue-green species which can effectively use nitrogen limitation to their advantage.

7. The fisheries in Cedar Lake are dominated by carp and other bottom feeding fish species which can effectively forage in highly turbid waters.

8. Data suggest that the high water column phosphorus concentrations in Cedar Lake are due largely to the release of phosphorus from sediments. Internal loading of phosphorus is estimated to account for 69 - 92% of the total loading of phosphorus to Cedar Lake.

9. The analysis of sediments and four species of fish for metals and PCB's detected no levels which exceeded known standards. Phosphorus concentrations in the sediments were measured to be highest in the upper 30 centimeters.

10. The most feasible restoration alternatives for restoring Cedar Lake are dredging, nutrient inactivation, dilution/flushing, biomanipulation, and do nothing.

11. Dredging of the upper 50 cm of Cedar Lake's silty-clay sediments would expose a sediment layer having phosphorus concentrations one-half those of the surficial sediments. This could reduce internal loading of phosphorus from sediments by 29%. However, internal loading following dredging would still be sufficient enough to cause eutrophic conditions (as determined by Vollenweider's relationships) in Cedar Lake. The volume of the dredged material thus removed is approximated as 900,000 cubic meters. Estimated cost of removing and disposing of this volume of material range from $1.5 million to $3.1 million, depending on the disposal sites used. Environmental impacts are relatively high with dredging and include: increased short-term water column turbidity, major disruption of Cedar Lake's benthic community, and possible disposal impacts.

12. Treating Cedar Lake's water with aluminum sulfate (alum) would cause water column phosphorus to precipitate out and settle to the bottom where the floc could provide a barrier to phosphorus release from the sediments. However, in well mixed lakes such as Cedar Lake, alum treatment can only be effective for 1-2 years, indicating that retreatment would be necessary to maintain effectiveness. Costs for a single alum treatment of Cedar Lake based on the maximum dosage to lower pH to 6.0 is approximately $225,000. Possible environmental impacts include: toxic effects of aluminum due to repeated treatment, changes in water column pH, and adverse effects on benthic organisms due to the settled floc at the mud-water interface.

13. Increasing the hydraulic flushing rate for Cedar Lake, by the addition of surface or groundwater low in phosphorus content, could effectively dilute present water column phosphorus concentrations. An adequate source of local water for this purpose could not be identified. This method would be feasible if the costs of pumping dilutional water over great distances is not too high. Expected benefits of dilution could be offset by increased phosphorus loading from the large volumes of dilution water, and by the release of phosphorus from sediments as the concentration gradient between sediments and overlying water is altered. Environmental impacts are largely related to the effects of phosphorus-rich effluent waters from Cedar Lake on downstream water bodies.

14. A biomanipulation program on Cedar Lake would restructure the lakes biological community by increasing piscivores and decreasing planktivores and benthivores, thus allowing zooplankton numbers to increase enough to control algae. Implementation of this program would require a complete fisheries renovation utilizing rotenone as the poisoning agent. Expected benefits include decreased algae, decreased phosphorus pumping due to rough fish, and increased transparency.

15. To do nothing at Cedar Lake would be the least costly method to employ and would involve the fewest additional environmental impacts. Although Cedar Lake has shown some qualitative improvements in water quality since the operation of the new wastewater collection system, the rate of improvement is difficult to assess with the present data base. The length of time until a non-eutrophic state is achieved could take as long as twenty five years due, in part, to the low flushing rate. The rate of improvement by this method cannot be adequately predicted without better knowledge of internal phosphorus dynamics.

16. The recommended restoration program for Cedar Lake is based upon a biomanipulation approach and includes a complete fisheries renovation, modifications to the lake's outlet structure, a one-time alum treatment, a one-time ban on high-speed motor boating in the spring, and a ban on live-bait fishing.

INTRODUCTION

Background

The Cedar Lake area was not settled until the mid 1830's due, in part, to the presence of more tillable soils to the west. At that time, the "Lake of the Red Cedars" was one of the largest natural bodies of fresh water in Indiana (Rhein et al. 1978). With the establishment of a railway in the 1870's, Cedar Lake rapidly became a popular resort area, with many of the vacationers arriving from Chicago by rail.

In the early 1870's a ditch was cut on the eastern side of Cedar Lake and an inlet stream near this ditch was rerouted into the ditch (Cedar Creek) for the purpose of lowering the lake level to reclaim land for farming. The lake level was lowered 8 to 12 feet by this action and was reduced in size by approximately 200 acres (Blatchley 1897; Evert Kincaid & Assoc. 1964). In a survey of Indiana lakes conducted around the turn of the century, Blatchley (1897) described Cedar Lake as being of good quality. Its area was reported as 748.8 acres and its maximum depth was 20 feet. The east and west sides of the lake had a sandy bottom, while the south end had a bottom composed of blue clays covered by approximately one foot of muck. Rooted aquatic plants were abundant, indicating that the water was transparent enough to permit their development.

Sweeney (1908) reported that in 1905-1906, the Indiana Commission of Fisheries was stocking the lake with both smallmouth and largemouth bass, and that 3,000 northern pike had been brought in from the Kankakee River.

Photographs on file at the Division of Water, Indiana Department of Natural Resources (1979) show that macrophytes were abundant in Cedar Lake into the early 1950's. Evidence that macrophytes may have been a problem at the lake is revealed in 1935 records which indicate that the Lake County Health Department spent $2,500 for the removal and burning of decaying vegetation (Great Lakes - Illinois River Basins Project 1963). Algal scums were evident on the lake in 1948 and by 1956, a major fish kill occurred which was caused by dense algal bloom. By this time, macrophytes in Cedar Lake were becoming uncommon.

In 1950, it was estimated that 3,900 people resided within the present day boundaries of the town of Cedar Lake (Rhein et al. 1978). On a typical summer day, as many as 25,000 tourists would also visit the lake (Doggett 1950). By 1960, the permanent population had grown to over 5700 with an additional large summer population. At this time, the watershed contained a sizable business community and more than 2,500 homes (Great Lakes-Illinois River Basins Project 1963). All of the residences had their own individual sewage treatment facilities and raw or inadequately treated sewage entering the lake was a common problem. Disagreeable algal blooms and very high fecal coliform bacterial counts had become common and the fisheries value of the lake had drastically declined.

Local efforts to chlorinate swimming areas and to apply algicides failed to provide a solution, so in response to the increasing problems, the Lake County Health Department and the Indiana Stream Pollution Control Board studied the lake in 1963 from a sanitation and biological standpoint. Their tests showed that the coliform bacterial counts of the lake were too high for swimming standards and in June of 1963, the Director of the Lake County Health Department issued a statement that Cedar Lake was unfit for swimming (Evert Kincaid, Assoc. 1964). The report of this investigation (Great Lakes - Illinois River Basins Project 1963) identified the following as causes of the water quality problems at Cedar Lake:

1. The drainage of raw and inadequately treated sewage through the use of septic tank wastewater disposal systems installed on undersized lots and in unsuitable soils; septic tank tile fields and seepage pits installed too near the shoreline; and, in some instances, a total lack of treatment;

2. The shallow depth of the lake which allows wind-induced turbulence to resuspend organic matter and nutrients from the sediments; and

3. Inadequate flow-through which allows continual build-up and concentrating of nutrients.

The study recommended the installation of a complete wastewater treatment system and the initiation of a long range program to restore the lake.

Due primarily to the social and economic aspects associated with the Lake County Health Department statement, many organizations were formed or strengthened with a view toward eliminating the pollution problem. Local attempts to improve the water quality of Cedar Lake continued. These included aeration, augmentation of lake levels with groundwater, and continued application of algicides, specifically copper sulfate. In the meantime, plans for a basinwide wastewater collection system were developed and construction began in 1972. The system, which transports wastewater to the Lowell Sewage Treatment Plant seven miles to the south, was accepted as being complete in late 1975 and the majority of users were hooked up by July 1977. Today, approximately 95% of the potential users in the area are hooked up (C. Walker pers. comm.).

Relationship to Other Projects

Since the the 1940's a number of individual efforts have been directed at improving the water quality of Cedar Lake. This study however, is the first attempt at long range planning and is consistent with other programs that have been proposed or developed in the Cedar Lake area.

Following a study in 1963 by the Lake County Health Department and the Indiana Stream Pollution Control Board, it was recommended that a complete wastewater treatment system be installed and that a long range program be initiated to restore Cedar Lake.

After a fisheries renovation program conducted by the Indiana Department of Natural Resources (DNR) in 1966 eventually failed, the DNR concluded that further attempts to improve Cedar Lake's fishery would be fruitless until the water quality in the lake was improved and fish screens were installed to prevent undesirable species from entering the lake via Cedar Creek.

Sanitary sewer lines were completed in 1974 and wastewater generated at Cedar Lake is currently being treated at the Lowell Sewage Treatment Plant. This has eliminated a major source of nutrient input to the lake.

The Cedar Lake Park and Recreation Plan recognizes the importance of a clean and aesthetically appealing Cedar Lake to the area's recreation needs. The development of new parks and other facilities is dependent upon the restoration of Cedar Lake.

CHAPTER 1: LAKE SETTING

1.0 LOCATION

Cedar Lake is located in west central Lake County, T34N, R9W, Sections 22, 23, 26, 27, 34 and 35. It lies approximately 4.5 miles southwest of Crown Point and forty miles southeast of Chicago. U.S. Route 41 (Wicker Street), Lake Shore Drive and Parrish Street, 133rd Avenue, Morse Street, and Cline Avenue provide the principal automobile access to Cedar Lake (Figure 1-1).

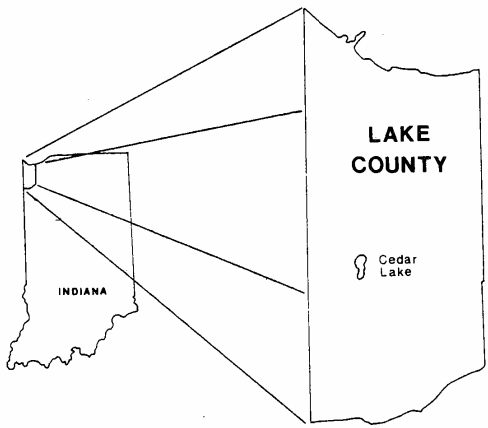


Figure 1-1. Location map.

1.1 LAKE MORPHOMETRY

Cedar Lake has a three-lobed shape that can be seen on the bathymetric map presented as Figure 1-2. The following morphometric parameters have been determined from the map:

Maximum Length	3.4 kilometers (2.1 miles)
Maximum Width	1.5 kilometers (0.9 miles)
Surface Area	316 hectares (781 acres)
Volume	$8.44 \times 10^6 m^3$ (6841 acre feet)
Maximum Depth	4.9 meters (16 feet)
Mean Depth	2.7 meters (8.8 feet)
Shore Line	9.5 kilometers (5.9 miles)
Shoreline Development Ratio	1.52

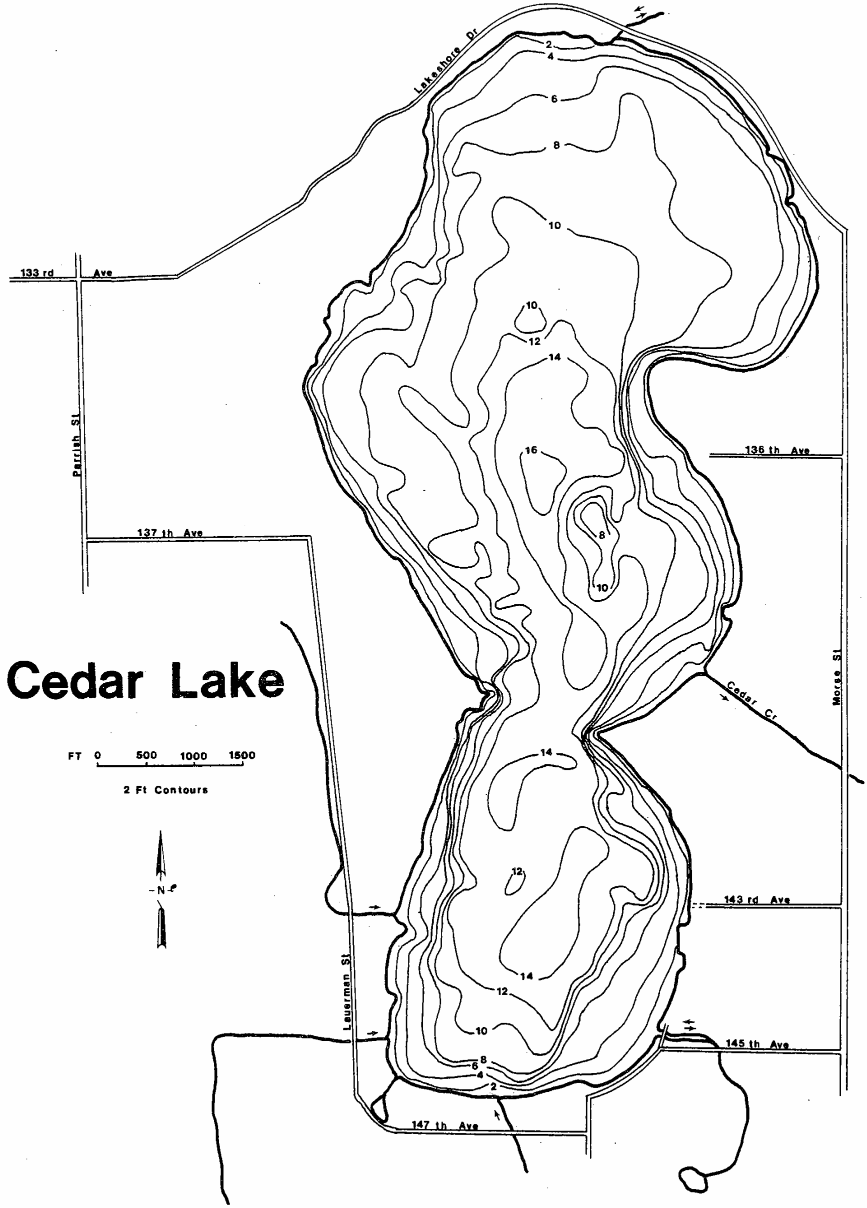


Figure 1-2. Bathymetric map.

The maximum length of Cedar Lake occurs along the north-south axis and the maximum width across the north basin. The maximum depth occurs in the middle basin. A hypsograph, which graphically represents the relationship between the surface area of a lake and its depth, is presented in Figure 1-3.

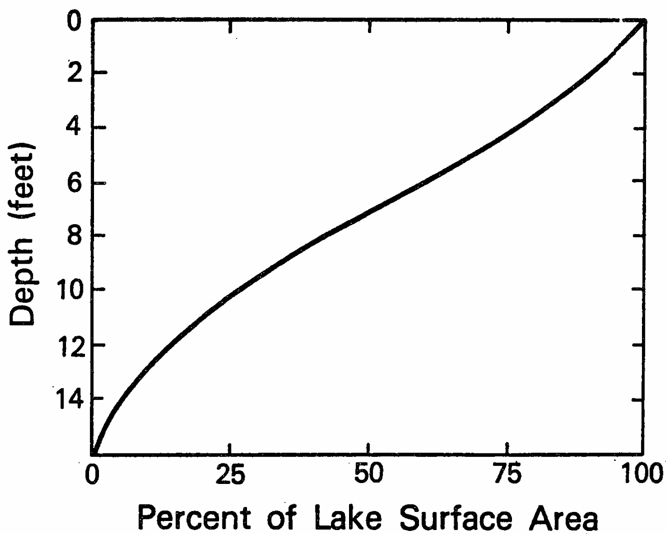


Figure 1-3. Hypsograph of surface area to depth relationship.

The graph illustrates a nearly linear relationship between percent area and depth for most of Cedar Lake except in the extreme shallows and deep areas, where there is slightly less relative area. This indicates that while Cedar Lake is shallow for its size, there is a rather even distribution between shallow and deeper waters.

Shoreline development is a ratio of the length of the shoreline to the length of the circumference of a circle of area equal to that of the lake. Very circular lakes approach the value of 1.0 while more elongated lakes have values exceeding 2 or 3. The value of 1.52 for Cedar Lake suggests that the shoreline is not overly convoluted due to bays or inlets.

1.2 DRAINAGE BASIN SIZE AND CHARACTERISTICS

Cedar Lake drains an area of approximately 4,500 acres (1841 ha) in size exclusive of the lake area itself (Figure 1-4). Within the

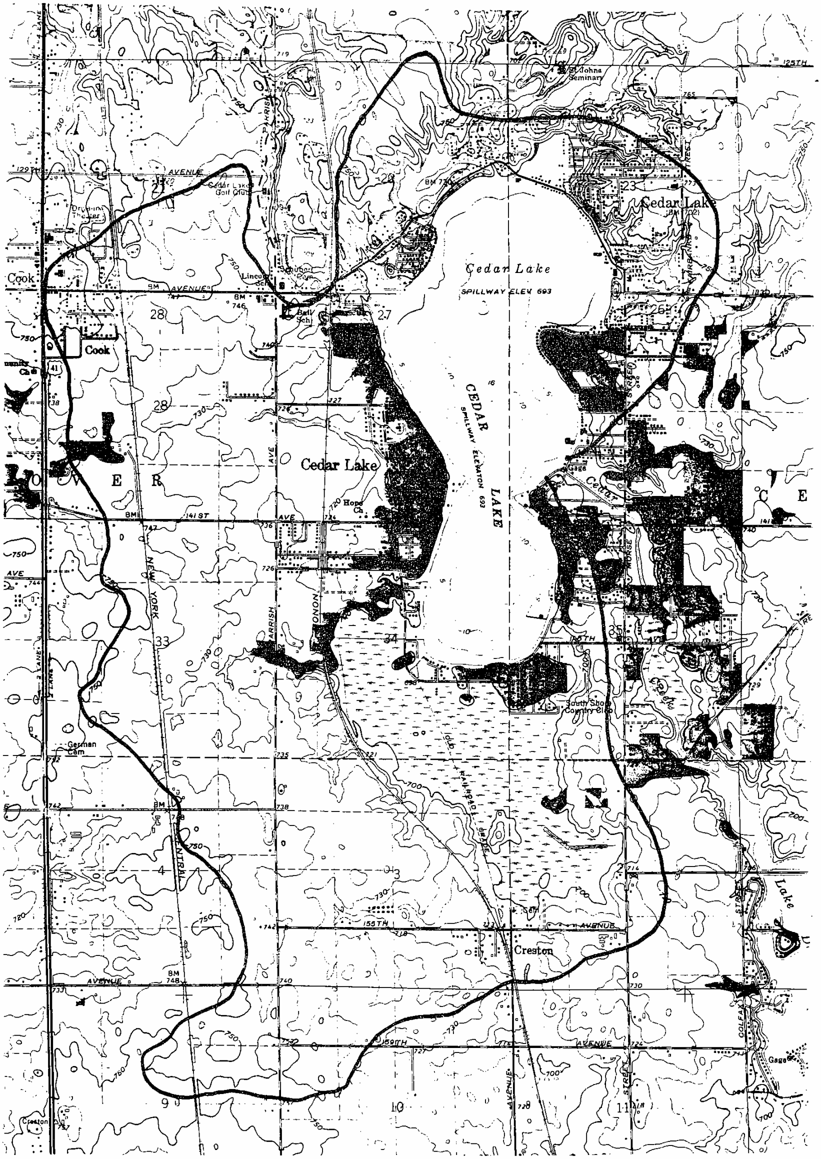


Figure 1-4. Cedar Lake drainage basin.

watershed there are six streams all of which cease to flow during dry periods. Three of these are considered inlets. In the past, Sleepy Hollow Ditch, an inlet at the west side of the lake, maintained flow over the entire year due to the effluent it received from the wastewater treatment plant for the Utopia subdivision which operated from 1956 to 1977. The two inlets on the south and southwest side drain a large 403 acre (163 ha) wetland, which, in turn drains approximately one-half of the drainage basin.

A stream on the southeast side connects Cedar Lake to a small golf course irrigation pond. Another stream at the northern end of the lake drains a small 14 acre (5.7 ha) wetland. Water in both of these streams has been observed to flow both into and out of the lake, depending on the season. When it does occur, streamflow is rather limited.

Cedar Creek, loated on the east side of the middle basin, is the only outlet to Cedar Lake. This creek is also an intermittent stream and generally has no flow during the summer months. The location and ephemeral nature of the streams associated with Cedar Lake provide for only limited hydraulic flushing.

1.3 LAND USE

Classes of land use are found in the following percentages within Cedar Lake's drainage basin: 4% forest lands, 9% wetlands, 24% urban lands, and 63% agricultural and open lands. The distribution of land use classes within the basin is illustrated in Figure 1-5.

The immediate shoreline of Cedar Lake is heavily developed with permanent and summer residences, a few businesses located primarily along the northest edge of the lake, and several marinas. Because of its origin as a resort community and because of the speculative manner in which the land was platted and sold, there is little planning evident in the layout of structures around the lake. As a result, dwellings are spaced very close together with many located on the very edge of the lake itself. There are approximately 2,600 dewellings in the town of Cedar Lake with an average lot size of 5,000 square feet (Evert Kincaid & Assoc. 1964). Approximately 400 dwellings are within 100 meters of the lakeshore.

The only free public boat ramp on Cedar Lake is a 200 foot wide piece of state owned and managed property on the extreme northern edge of the lake. Other publicly owned properties include: a long and narrow strip of land along the northwest shore, a 150 foot wide strip of land along the northeast shore, and 18.9 acres on the east shore of the middle basin on which the Town Hall is located. These and several other properties have been recognized in the Cedar Lake Park and Recreation Plan (Rhein et al. 1978) as potential public park locations (Figure 1-6).

Two wetland areas of significance lie within Cedar Lake's drainage basin. One, a 14 acre (5.7 ha) wetland lies at the norhern edge of the lake. A small channel connects it to Cedar Lake although it has little or no flow for most of the year. Another

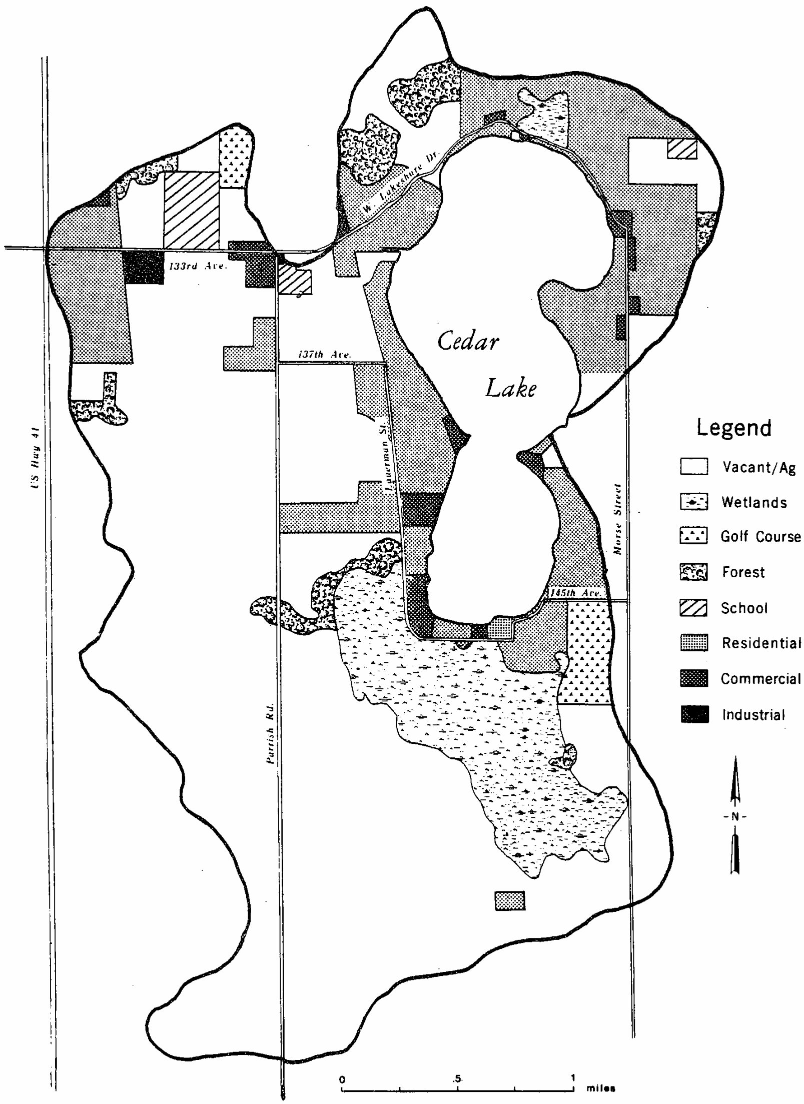


Figure 1-5. Land use classes in Cedar Lake's drainage basin.

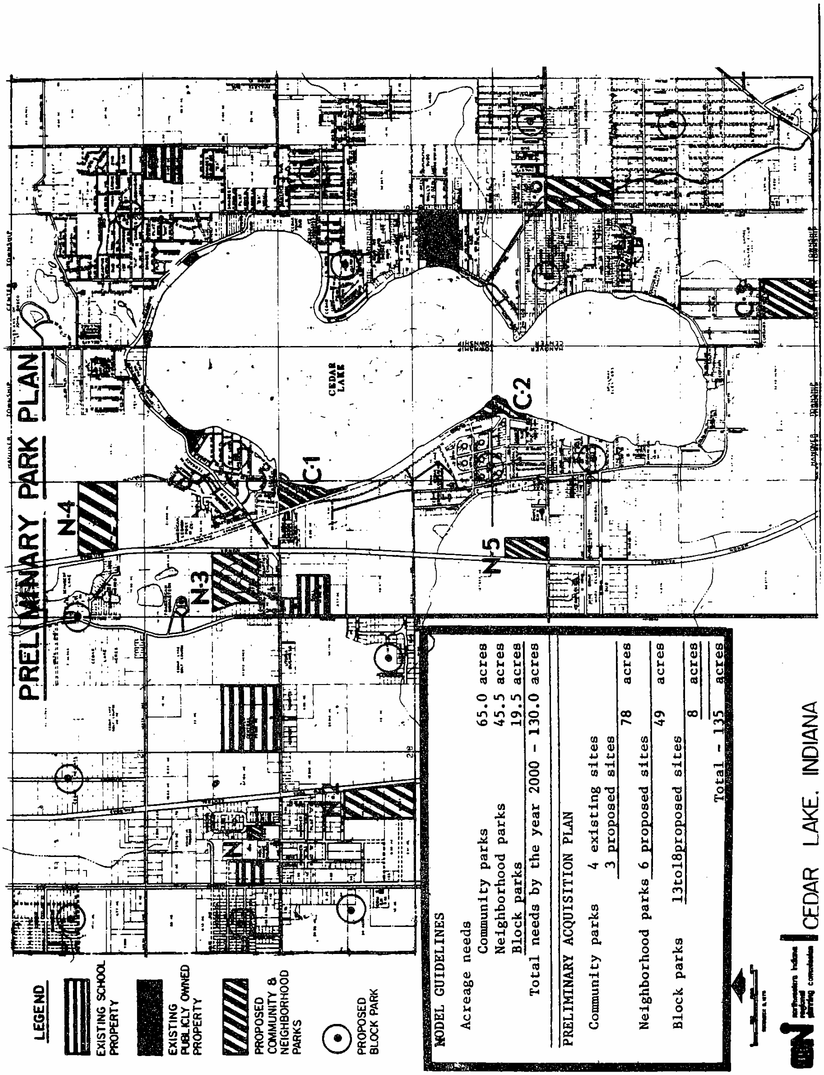


Figure 1-6. Preliminary park plan.

wetland, known as Cedar Lake Marsh, occupies 403 acres (163 ha) to the south of the lake. The relationship of these wetlands to Cedar Lake is discussed in greater detail in Section 2.8.

The remaining area within the drainage basin is composed of agricultural lands. Corn is the predominant crop cultivated with smaller acreages devoted to soybeans, hay, and winter wheat.

1.4 CLIMATE

The climate in northern Lake County is characterized by wide variations in temperature that are typical of areas in the middle latitudes of the interior United States. Winds from Lake Michigan tend to moderate seasonal extremes in temperature and affect some aspects of precipitation. Winds, however, blow most frequently from the southwest except occasionally in winter when prevailing winds are from the northwest. Precipitation is fairly well distributed throughout the year. Climatological data are summarized in Table 1-1.

Table 1-1. Summary of monthly climatological data for the Cedar Lake area.

	Average Temperature (°F)	Maximum Precip. (in.)	Minimum Precip. (in.)	Average Precip. (in.)	Mean Wind Speed (MPH)	Mean Maximum 1 Min Duration Wind Speed (MPH)[2]
January	19.2	4.60	.72	2.09	12.8	36
February	25.1	4.78	.70	2.00	12.3	32
March	37.3	5.69	1.76	3.44	12.6	32
April	48.3	6.62	.72	4.40	11.7	32
May	58.8	7.49	1.83	4.64	9.8	29
June	68.8	8.33	2.56	4.69	9.4	28
July	72.7	6.48	1.49	4.47	8.4	27
August	70.3	7.70	1.73	3.88	7.6	25
September	63.7	7.64	1.04	4.17	8.1	24
October	51.6	3.45	1.34	2.40	9.2	26
November	38.7	4.57	1.31	2.57	10.8	28
December	26.6	6.29	.80	3.21	11.3	29

[1] Collected at Lowell, IN (1971-1978).

[2] Collected at South Bend Airport (1971-1977).

1.5 GEOLOGY AND SOILS

Cedar Lake lies in what is geologically known as the Valparaiso Morainal Area, a complex system of rolling hills extending in an arc from northeastern Illinois, through northwestern Indiana, and into southwestern Michigan. The main crest of the moraine passes along a ridge about a quarter of a mile north of Cedar Lake. The Valparaiso

Moraine is a composite of several end moraines, one superimposed atop the other, laid down due to minor fluctuations of the terminus of the Lake Michigan lobe of the Wisconsinan Age of glaciation approximately 14,000 years ago (Figure 1-7). The bulk of the upper till, which ranges in thickness from 15 to about 50 feet, is a clay loam material. An older till, deposited by the advancing glacier, lies beneath the upper till at depths ranging from 15 to more than 100 feet. The lithology and texture of this lower till is similar to that of the upper. A layer of sand and fine gravel lies between the upper and lower tills across the southern half of the Valapraiso Moraine. This coarse sediment unit is outwash of the glacial-recessional stage that occurred between the deposition of the upper and lower tills (Hartke et al. 1975).

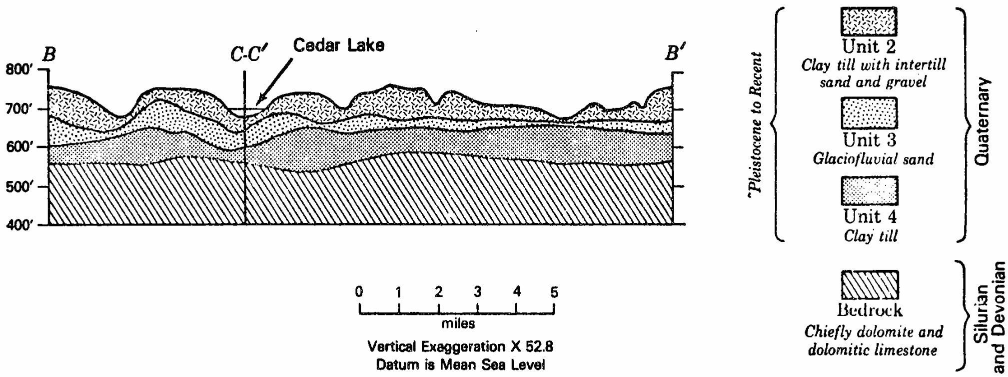


Figure 1-7. Generalized section showing lithologic units in glacial drift of Lake County. B-B' is a west to east transectthrough Lake County. Cedar Lake is at C-C'. From Rosenshein (1962).

The moraine is dotted by numerous small lakes that formed in ice-block depressions called kettle holes. Cedar Lake is the largest of these "ice-block" lakes in northern Indiana. The Valparaiso till plain of the Cedar Lake area is rather irregular and narrow with numerous divides and many short deep slopes. Approximately one-third of the area is depressed and does not have good outlets for water and is, consequently, covered with dark, poorly drained soils (Evert Kincaid & Assoc. 1964).

A generalized soil map for the Cedar Lake drainage basin is presented in Figure 1-8. The primary soil types to be found in the immediate vicinity of the lake belong to the following mapping units: Carlisle muck (Ca), Blount silt loam (BlA), Elliott silt loam (El), Milford silt loam (Mo), Morley silt loam (Mu), Pewamo silty clay loam (Pc), and Urban land (Ur). Some pertinent characteristics of these soils are given in Table 1-2.

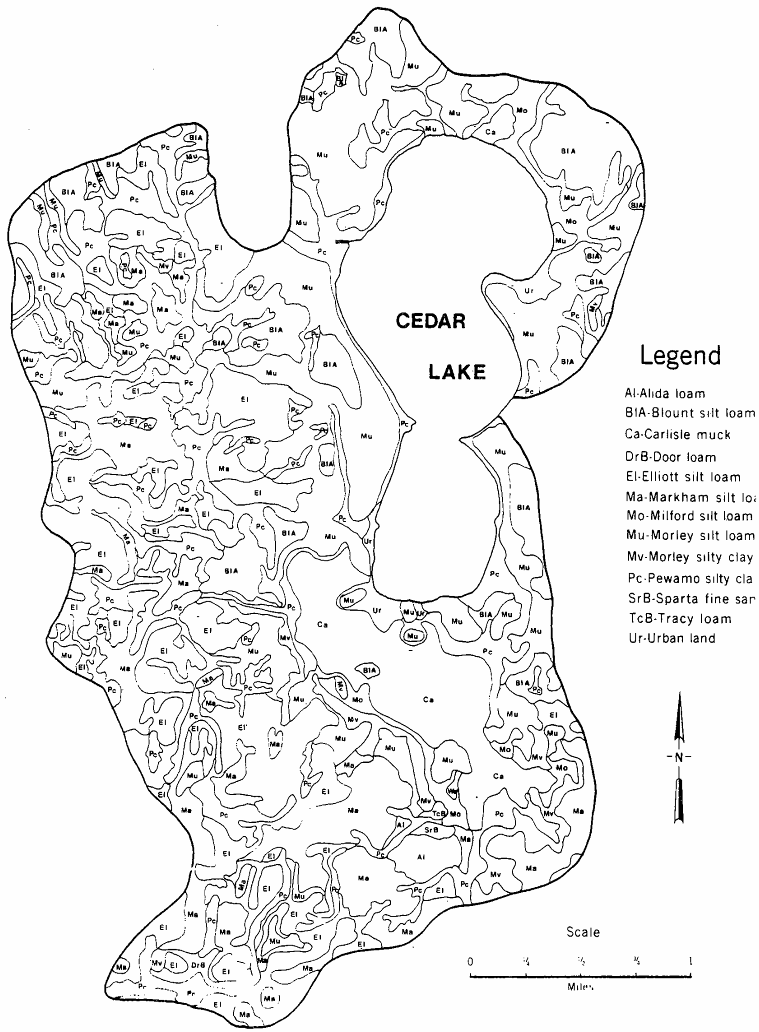


Figure 1-8. Soils map of Cedar Lake's drainage basin.

Table 1-2. Selected characteristics of soils in the Cedar Lake area.

Soil Series and Map Symbol	Depth to seasonal high water table (ft.)	Depth from surface (in)	Permeability (in/hr)	Septic tank disposal field limitations
Blount: Bl	1-4	0-36	0.06-2.00	Severe: Seasonal high water table; slow permeability.
Carlisle: Ca	0-1	0-60	0.63-2.0	Severe: High water table; depressional.
Elliott: El	1-4	0-15	0.63-2.00	Severe: Seasonal high water table, slow permeability.
Milford: Mo	0-1	0-17	0.20-0.63	Severe: High water table and ponding; slow permeability
Morley: Mu	4	0-8	0.63-2.00	Severe: Moderately slow to slow permeability; large filter beds necessary on site investigation needed.
Pewamo: Pc	0-1	0-42	0.20-0.63	Severe: High water table and ponding; slow to moderately slow permeability

The combination of slow permeability and high water table levels cause serious restrictions in the use of these soils for septic tank disposal fields. Because of these conditions, the Indiana State Board of Health (ISBH) has determined that in the area of Cedar Lake, a minimum lot size of 18,000 square feet is necessary for the proper and effective operation of individual septic fields (Evert Kincaid & Assoc. 1964). The average lot size per residential home in the Cedar Lake area is only 5,000 square feet, less than one-third the size recommended by the ISBH. Lot sizes of many lakeshore homes are considerably less than 5,000 square feet. This combined with the short setbacks of many homes near the shoreline, suggests that inadequately treated sewage has been entering Cedar Lake from septic systems.

1.6 DEMOGRAPHY AND ECONOMIC STRUCTURE

Population trends and forecasts are important in considering the future demands which may be placed on Cedar Lake's recreational and environmental resources. In a park and recreation plan for the Town of Cedar Lake, the Northwestern Indiana Regional Planning Commission (NIRPC) (Rhein et al. 1978), has projected that the 1975 population fo the Town of Cedar Lake will nearly double by the year 2000; increasing from 7,747 to 13,000 (Table 1-3). Increased building activity and future annexation were two factors given to explain the population projection. It is possible that a successful restoration effort for Cedar Lake could affect these forecasts.

Table 1-3. Population of the Town of Cedar Lake[1].

Year	Population	Average Annual Change	Average Annual Percent Change
1950 (Population)[2]	3,907	--	--
1960 (Population)[2]	5,766	186	4.8
1970 (Population)	7,589	182	3.2
1973 (Population)	7,689	36	0.5
1975 (Population)	7,747	25	0.3
1980 (Forecasts)	9,000	251	3.2
1990 (Forecasts)	11,500	250	2.8
2000 (Forecasts)	13,000	150	1.3

[1]From Rhein et al. (1978).

[2]Estimated from U.S. Census figures for unincorporated areas.

No statistics are available concerning the economic structure of the Cedar Lake population. However, a 1964 study prepared for the Lake County Plan Commission by Evert Kincaid and Associates, Inc. (1964), provides some insite to economic conditions in the Town of Cedar Lake. A housing survey conducted as a part of this study indicated that 15% of the major structures in the study area were dilapidated and 31% were deteriorating. The majority of these structures were located in the immediate lakeshore area. No current data are available to update this information on housing conditions.

1.7 ACCESS AND RECREATIONAL USE

Most recreational visitors travel to Cedar Lake by automobile although Greyhound bus service to the lake area is scheduled twice daily. The lake area is not served by passenger rail service.

Direct public access to Cedar Lake is provided by a state-owned public access on the northern edge of the lake. Facilities include a boat launching ramp and parking area. No beach or restroom facilities are provided. Additional access to Cedar Lake is available for a fee from a number of marinas surrounding the lake.

Despite recent water quality problems, Cedar Lake remains as one of the major aquatic recreational areas in Lake and Porter counties. A large number of lake users travel to Cedar Lake from northeastern Illinois as well. Activity on the lake is more extensive from Memorial Day to Labor Day. Major activities include power boating, water skiing and, to a lesser extent, sailing. Although the lake's fisheries are somewhat depressed, fishing is still frequently observed.. Swimming in Cedar Lake is limited due, in part, to the lack of public beaches and the lake's current water quality.

Recreational activity is not restricted to only the summer months as ice fishing, snowmobiling, and cross country skiing are popular during the winter months. Several duck blinds were observed on the lake giving indication of some level of fall hunting.

1.8 MAJOR LAKES WITHIN A 50-MILE RADIUS OF CEDAR LAKE

There are a number of other lakes within a 50-mile radius of Cedar Lake that are suitable for aquatic-based recreation. The largest of these is Lake Michigan, approximately 18 miles to the north. Lake Michigan has a somewhat different recreation base than the smaller inland lakes such as Cedar Lake. Size precludes the use of much of Lake Michigan by recreational watercraft. This restriction is intensified by unfavorable weather conditions and the lack of an adequate number of harbors of refuge (Great Lakes Basin Commission 1975). These conditions can require the use of larger water craft which may be beyond the means of the majority of potential lake users. In addition, cool water temperatures restrict body contact for swimming and water skiing during much of the year.

Other lakes in the area are more capable of supporting recreational activities similar to those at Cedar Lake. Most of these lakes, however, are smaller and have recreation potentials which are similarly limited by poor water quality. Table 1-4 presents physical and chemical data for major lakes within a 50-mile radius of Cedar Lake. The data presented represent a single sample from each lake collected during the period of June to September over a five year study of Indiana lakes (Torke and Senft 1979).

Table 1-4. Physical and chemical parameters for Indiana lakes over 100 acres within a 50-mile radius of Cedar Lake. Brackets ( ) indicate numerical ranking among all lakes studied.

Lake	Distance (mi) and Direction from Cedar Lake	Size (acres)	Maximum Depth (ft)	Mean Depth (ft)	Average Water Column total P Concentration (mg/l)	Secchi Depth (ft)	Eutrophication Index (75 maximum)
Cedar	0	781 (21)	16.0 (276)	8.6 (282)	.52 (5)	1.2 (336)	70 (8)
Dalecarlia	2 SE	193 (66)	----	6.0 (322)	.30 (35)	1.0 (345)	51 (103)
George (Hobart)	13 NE	282 (49)	14.0 (291)	5.0 (345)	.19 (58)	1.0 (344)	55 (71)
Wolf (main Indiana basin)	20 NW	385 (40)	15.0 (284)	5.0 (344)	.09 (125)	----	58 (53)
Pine (La Porte)	39 NE	282 (48)	----	13.0 (186)	.03 (313)	10.0 (57)	22 (324)
Bass	44 ESE	1400 (11)	30.0 (182)	10.0 (255)	.70 (3)	2.5 (298)	39 (177)

*After Torke and Senft (1979)

CHAPTER 2: DESCRIPTION OF EXISTING ENVIRONMENT

2.0 INTRODUCTION

An extensive field sampling program was established to collect the necessary data from which restoration recommendations could be based. Because of the lack of an extensive existing data base, field work was required in a number of areas. These include: lake, stream, and precipitation water quality; streamflow; sediment analysis; and algae, macrophyte, and fish abundance. Water samples were collected for analysis monthly during March, April, and October, 1979, and bi-weekly from May through September, 1979, when lake conditions were expected to be most variable. Streamflows were recorded during regular sampling trips when flow was measurable. Sampling for sediment analysis, macrophytes, and fish was conducted as needed. The locations of sampling sites are indicated in Figure 2-1.

2.1 HYDROLOGY

Cedar Lake is a "kettle lake" having a small drainage area and is fed by runoff from local precipitation, by effluent flow of groundwater to the lake, and by springs (Vig 1963). The hydrology of Cedar Lake is complicated due to the lake's position near the north-south continental drainage divide. These factors result in seasonal fluctuations in the lake's water level which is uncharacteristic of most natural lakes in Indiana.

2.1.1 Surface Water

Using Birge and Juday's (1934) definition, Cedar Lake is classified as a drainage lake since it has both a surface inlet and outlet. Because of its small drainage basin, surficial flow into and out of the lake is highly seasonal in nature. Placing permanent streamflow gauges on the three inlet streams of Cedar Lake was beyond the scope of this project. Instead, streamflows were measured only during regular sampling trips. Only three measurements were possible due to the variability of flow. Streamflows as measured, are summarized in Table 2-1. the volume of surficial streamflow into Cedar Lake cannot be calculated from these data, however the data suggest that surface flow is not a major source of water to Cedar Lake.

The only outlet to Cedar Lake is Cedar Creek which discharges from the middle basin of the lake. A lake level control structure is located at the outlet and is maintained by the U.S. Geological Survey. The current dam was constructed in the late 1930's, replacing an older structure. The new structure is designed to maintain a maximum lake level of 693.00 ft. M.S.L., or one foot higher than the former structure.

The new structure was recommended because previous rainstorms had been great enough to rapidly raise the lake elevation, causing downstream flooding. The new structure is designed to maintain the

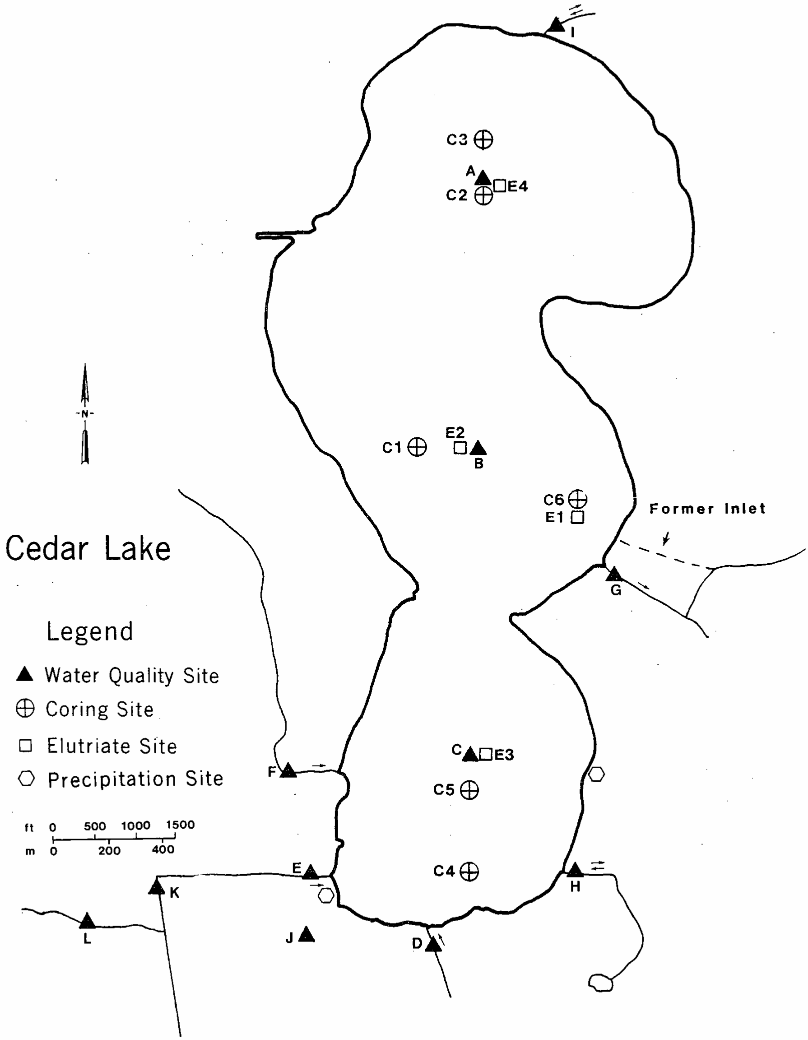


Figure 2-1. Location of sampling sites on Cedar Lake.

Table 2-1. Measured flows occurring in inlet streams to Cedar Lake during project period (m^3/sec).

Stream	10 March 79	11 May 79	25 May 79
D	0.74	0.09	0.11
E	0.22	0.04	no flow
F (Sleepy Hollow Ditch)	0.19	0.02	no flow
Former Inlet	-	0.03	no flow

lake level at spillway elevation during the maximum three year, twenty-four hour storm event (U.S. Geological Survey, unpublished).

Lake elevation records for Cedar Lake are available from the U.S. Geological Survey from August 9, 1943 to date. During the twenty year period from 1943-1963, the following levels have been determined (Great Lakes - Illinois River Basins Project 1963):

Gage datum	- 2.90 feet
Maximum level	- 4.23 feet (Mar. 16, 1944)
Minimum level	- 1.75 feet (Nov. 14, 19, 20, 1956)
Average level	- 2.91 feet
Max. - Min.	- 2.48 feet

The elevations since 1963 have remained within these ranges.

2.1.2 Groundwater

A network of groundwater observation wells could not be installed as part of this project. However, a number of investigations have been conducted in Lake County over the past years which have aided us in understanding regional and in some cases, local groundwater characteristics.

Three separate hydrologic systems (aquifers) occur in the Cedar Lake area. These are: 1) an unconsolidated system (0-150 feet below the surface), 2) a shallow bedrock system (150-350 feet) and 3) a deep bedrock system (below 1,300 feet) (Hartke et al. 1975). The systems differ in depth, geology, and water quantity and quality. There is also little, if any, direct hydraulic connections between the three aquifers.

Water quality in the unconsolidated aquifer, into which many private wells are located, is somewhat poor in the Cedar Lake area, due to slow percolation and increased contact of the groundwater with the overlying till. Sulfate (SO_4) concentrations range from 150-250 mg/l, hardness (as $CaCO_3$) from 500 to 750 mg/l, and iron from 1.5 to 2.5 mg/l (Hartke et al. 1975).

Many private wells around Cedar Lake are being drilled into the shallow bedrock aquifer to depths of 300 feet. Groundwater from this aquifer in the Cedar Lake area contains sulfate ranging from 50 to 150 mg/l, hardness from 50-500 mg/l, and iron 0.5 mg/l. Water yields from this aquifer are variable because of the nature of its porosity. Areas of solution features and fractures of joints are difficult to predict; therefore, well placement is critical (Hartke et al. 1975).

Cedar Lake is known as a water table lake, which means that the lake is hydrologically connected to the water table. This can perhaps be better illustrated in Figure 2-2 which shows that the potentiometric surface of the unconsolidated aquifer is 0 at the lake's surface. In practical terms, this means that when the water table is low (as in a dry summer), Cedar Lake's water level can be expected to be low. When the water table is high (for example, after being recharged in the spring), the lake level is high. This phenomenon, along with the lake's small surficial drainage area, causes large fluctuations in Cedar Lake's water level.

The importance of groundwater flow to Cedar Lake is limited by a number of possible factors. First, Cedar Lake is situated in a glacial valley covered with a nearly impervious layer of mostly clay drift material (Blatchley 1897; Vig 1963). Well logs indicate that this clay layer is generally thinnest in the northeast, where sand outcrops near lake elevation height, and thickens to the west and south. In some parts of the lake, the clay material exceeded five maters (16 feet) in depth (see Figure 2-24). This clay confining layer restricts infiltration of water into Cedar Lake from below.

Secondly, the shallow groundwater aquifer in the area must be recharged by precipitation slowly infiltrating through the clay confining material which lies over much of the aquifer. This slow recharge rate is further hindered by deforestation, development, and artifical drainages around the lake which cause precipitation to run off rather than infiltrate the soil, a problem that Blatchley recognized in 1897.

Thirdly, the groundwater slope in the area is very shallow. Groundwater, like surface water, moves in response to gravity from regions of high to low potential, along flow lines which are perpendicular to the potentiometric surface lines illustrated in Figure 2-3. The gradient between these potentiometric lines is rather flat in the area around Cedar Lake, approximately five feet per mile. This flat gradient along with the clayey till results in slow lateral groundwater movement through the region.

Finally, increased development of the groundwater aquifers around Cedar Lake by private and public wells, has further decreased the amount of groundwater available to flow into the lake.

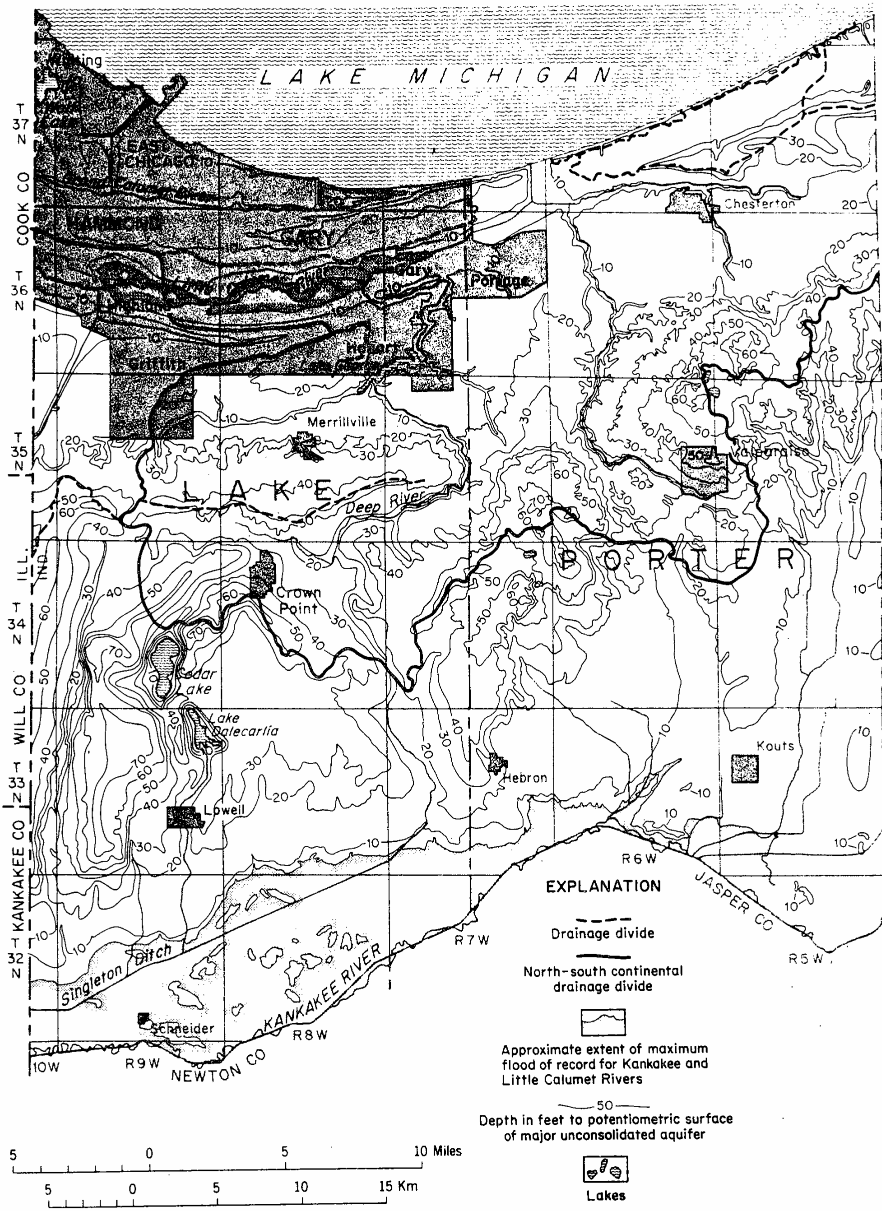


Figure 2-2. Map showing surface and subsurface hydrologic features in Lake and Porter Counties. From Hartke et al. (1975).

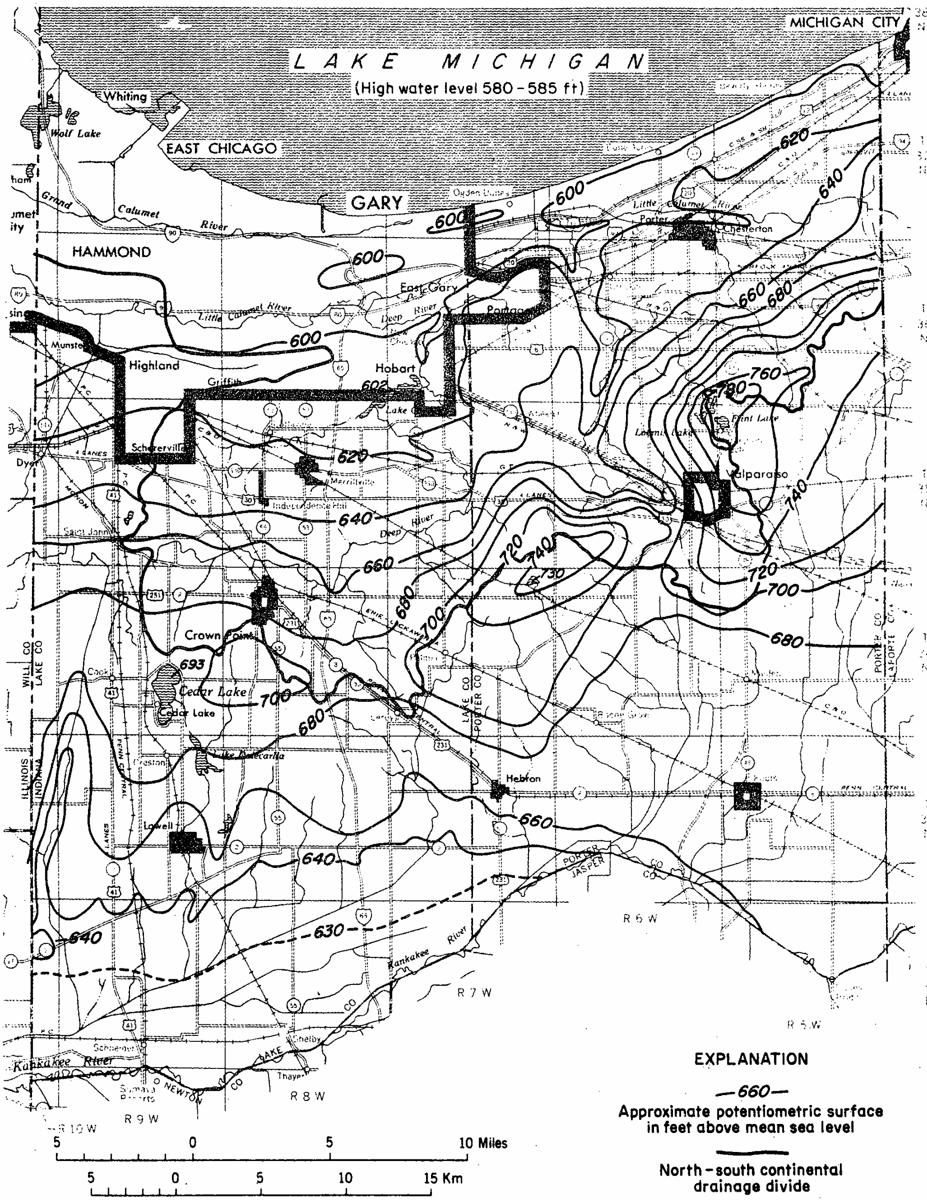


Figure 2-3. Map showing potentiometric surface of unconsolidated aquifer. From Hartke et al. (1975).

2.2 WATER QUALITY - LAKE

Three sampling sites were established in Cedar Lake to collect samples for water quality and algae analyses. The sites are located in the middle of each of the three basins (Figure 2-1). At each site during 1979, water samples were collected with a one liter Kemmerer sampler at three depths: 0.5 m below the surface, middle depth, and 0.5 m off the bottom. All samples were collected in the morning of each sample date except on May 25, 1979 when extremely high winds forced the postponement of sampling until late afternoon. All water samples were analyzed for the following water quality parameters:

1) temperture
2) dissolved oxygen (D.O.)
3) pH
4) alkalinity
5) conductivity
6) soluble reactive phosphorus (SRP)
7) total phosphorus (TP)
8) ammonia nitrogen
9) nitrate nitrogen
10) total Kjeldahl nitrogen (TKN)
11) chlorophyll _a_
12) turbidity
13) Secchi disc transparency

Detailed descriptions of the analytical procedures used are presented in Appendix A.

Additional water samples were collected from lake site C only, during 1982, as a check on the lake's water quality status in relation to 1979's data.

Weather conditions during each of the water quality sampling trips are summarized in Table 2-2. These data are presented because they are closely related to certain lake parameters such as lake mixing, turbidity and water temperature. The effects of weather conditions on some water quality parameters can be seen in the data.

Temperature and dissolved oxygen data indicate that Cedar Lake only temporarily stratifies during periods of calm weather during the summer. Thus, for the analysis that follows, temperature and dissolved oxygen data are presented from all depths and other parameters are graphically presented as means of the three depths measured. Fecal coliform bacteria data were provided by the Lake County Health Department (files). The original data for each sample date are presented in tabular form in Appendix B. All data presented are from the 1979 study unless otherwise indicated.

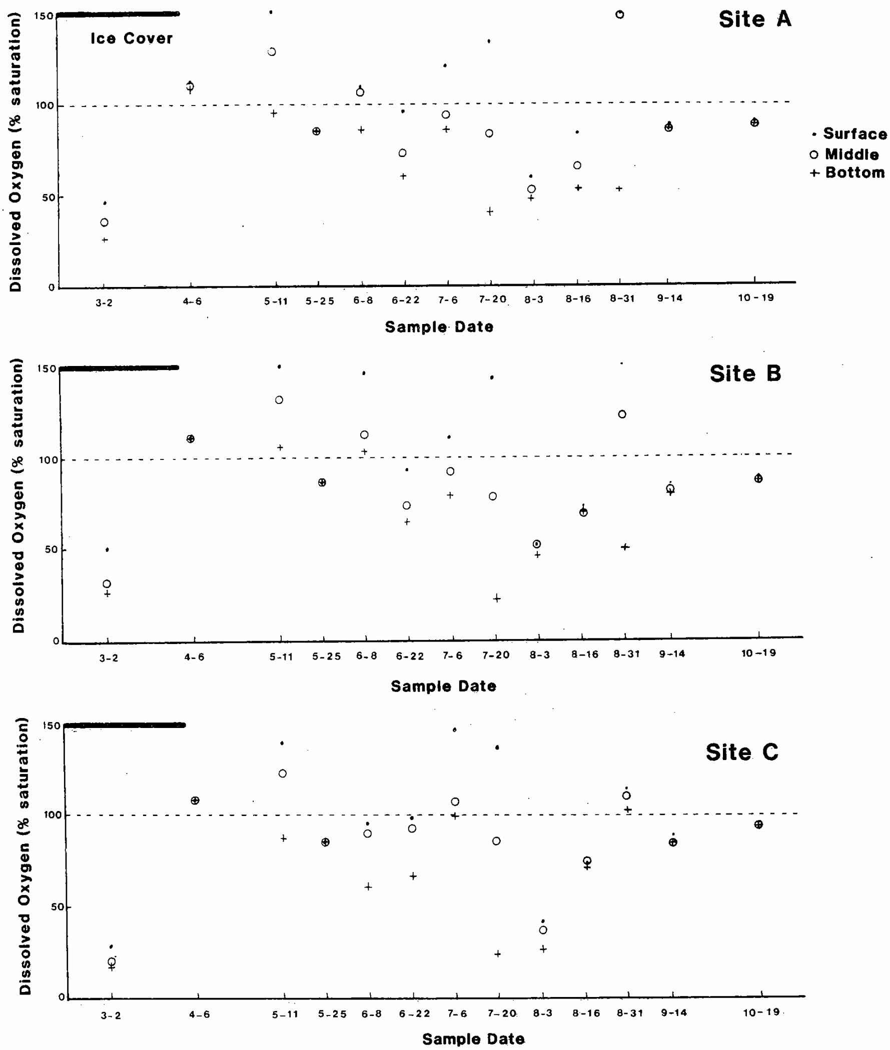


Figure 2-5. Dissolved oxygen saturation values for Cedar Lake sampling sites in 1979.

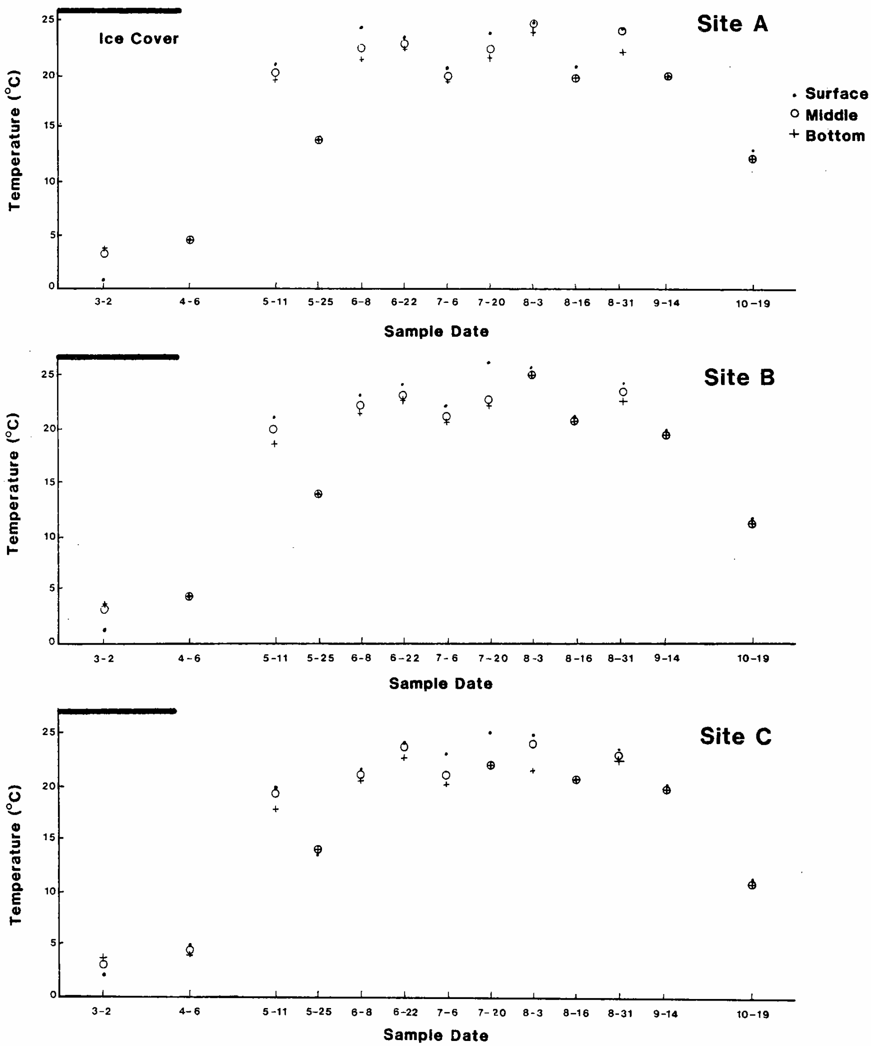


Figure 2-6. Temperature values (°C) for Cedar Lake sampling sites in 1979.

depth and thus would be extremely difficult to detect using a dissolved oxygen probe, without disturbing the steep oxygen gradient.

A drop in dissolved oxygen throughout the entire water column occurred on August 3. This may have been associated with an algae die-off during this period (See Section 2.6.1). Chlorophyll a content of the water was also reduced on this date giving further indication of a reduction in the standing crop of phytoplankton (Figure 2-17).

Temperature and oxygen characteristics of Cedar Lake indicate that complete mixing (holomixis) occurs throughout the open-water period of the year. Summer oxygen data indicate that bottom waters are replenished by diffusion of oxygen from the surface layers, which is accelerated by wind mixing. Stable thermal stratification was not observed during the period of study.

Considering that the lake is topographically exposed to the prevailing winds and has a large surface area to mean depth ratio, wind action is a sufficient force to cause complete mixing (Hutchinson 1957). The maximum difference between surface and bottom water temperatures during the open water period was only 4°C, occurring on July 20 at Site B. This vertical variation was due to hot, calm weather which heated only the surface water and restricted vertical mixing. This stratification, although only temporary, may regularly occur at other times during similar weather conditions. This does not represent a stable, stratified lake profile.

2.2.2 Alkalinity, Conductivity, and pH

Alkalinity samples were unaltered, stored on ice upon collection and titrated with N/44 acid to pH 4.3 immediately on arrival at the laboratory. Specific conductance was measured in the field using a temperature correcting conductivity meter and pH measurements were made in the field with a selective ion meter and a combination glass and reference electrode. A detailed description of analytical procedures used is presented in Appendix A.

Alkalinity measures the quantity of compounds, usually bicarbonate and carbonate ions, which allow water to resist large fluctuations in pH. This buffering action is important because it ensures a relatively constant environment for biological activity. Alkalinity results (Figure 2-7) indicate that Cedar Lake is moderately well buffered and is typical of lakes which develop on glacial till. The measured alkalinity values ranged from about 105 mg/l ($CaCO_3$) in early May to about 140 mg/l ($CaCO_3$) in early August. The observed seasonal alkalinity changes probably result from increased biological production that occurred throughout the spring and summer.

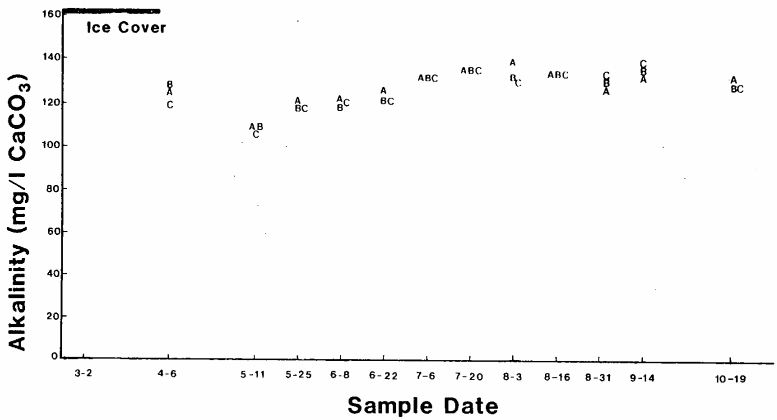


Figure 2-7. Averaged alkalinity values for Cedar Lake sampling sites in 1979.

Specific conductance is a measure of the ability of water to conduct an electrical current. It is an indirect measure of the concentration of ions present in the sample. A change in conductivity indicates a corresponding change in total ion concentration (e.g. cations: calcium, magnesium, potassium, sodium; anions: sulfate, chloride, carbonate). Conductivity of water sampled from Cedar Lake (Figure 2-8) below the ice in the late winter ranged between 450-500 umhos/cm. During the open water period, conductivity ranged between 350-420 umhos/cm and increased slowly through the spring and summer. This increase parallels an increase in alkalinity and is caused by increased dissolved organic and inorganic material that often accompanies increases in biological productivity.

The pH value is a measure of hydrogen ion activity. The range of pH in most open waters that are buffered by bicarbonate ions is between 6 and 9. The pH measurements from Cedar Lake in 1979 ranged from 6.5 to 9.2 (Figure 2-9). The pH values during the ice-free season are one to two pH units higher than under ice cover, due to increased photosynthetic activity during this period. The scatter of pH values between 7.5 and 9.0 during the open water season occurs because the measurement is sensitive to biological activity and can change diurnally and from day to day.

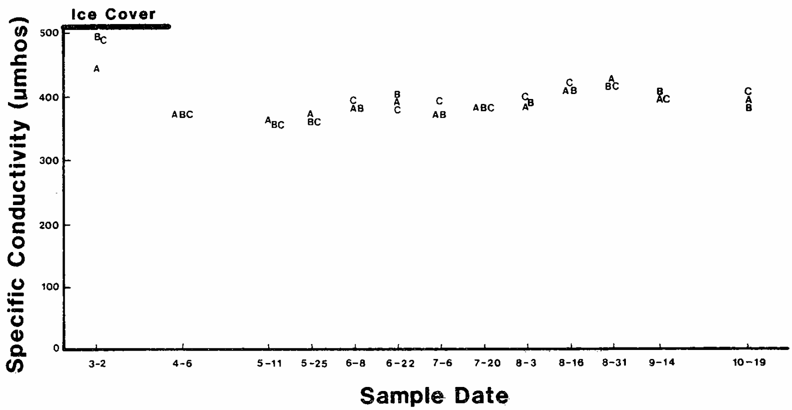


Figure 2-8. Averaged specific conductivity values for Cedar Lake sampling sites in 1979.

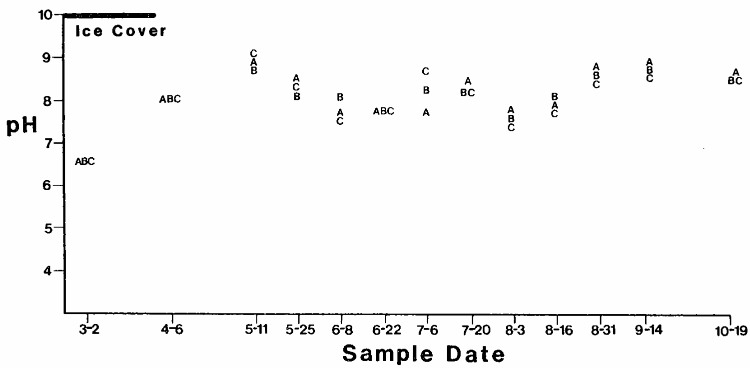


Figure 2-9. Averaged pH values for Cedar Lake sampling sites in 1979.

2.2.3 Phosphorus

Phosphorus samples were collected in acid-washed Pyrex bottles, stored on ice in the field and refrigerated at 4°C on arrival at the laboratory. Soluble reactive phosphorus (SRP) samples were filtered in the field, while total phosphorus (TP) samples were unaltered. SRP was analyzed immediately upon return to the laboratory, while TP was analyzed within a week of collection. Analysis of phosphorus was done by two variations of the phosphomolybdenum blue method. A detailed description of analytical procedures used is presented in Appendix A.

Total phosphorus concentrations of most unpolluted lakes are between 10 and 50 ug P/l (Wetzel 1975). Total phosphorus concentrations in Cedar Lake (Figure 2-10) appear annually to average greater than 100 ug/l and thus indicate hypereutrophic conditions (Vollenweider 1968). The 1979 spring turnover concentration of total phosphorus is greater than 150 ug/l and values for the rest of the spring are between 100 and 200 ug/l. Total phosphorus began to increase in concentration in June and continued to do so through August to a maximum value around 350 ug/l.

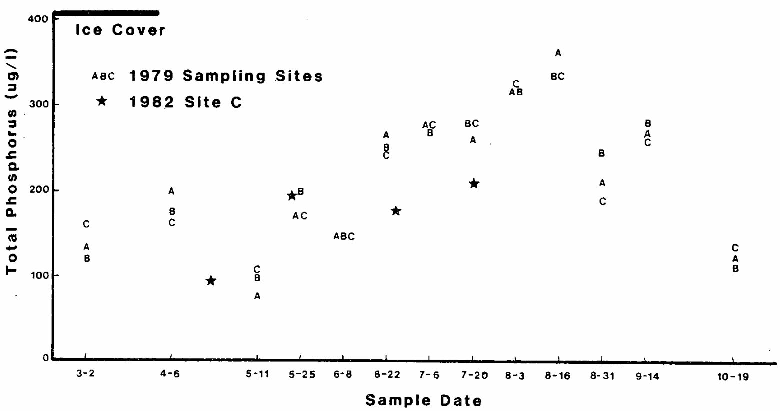


Figure 2-10. Averaged total phosphorus concentrations for Cedar Lake sampling sites in 1979 and 1982.

Soluble reactive phosphorus (SRP) is the form of phosphorus that is biologically available to phytoplankton. SRP concentrations in Cedar Lake (Figure 2-11) are low at spring turnover and exhibit small increases in concentration through the spring and large increases during the summer months. A maximum value of about 180 ug/l was recorded on August 3, 1979.

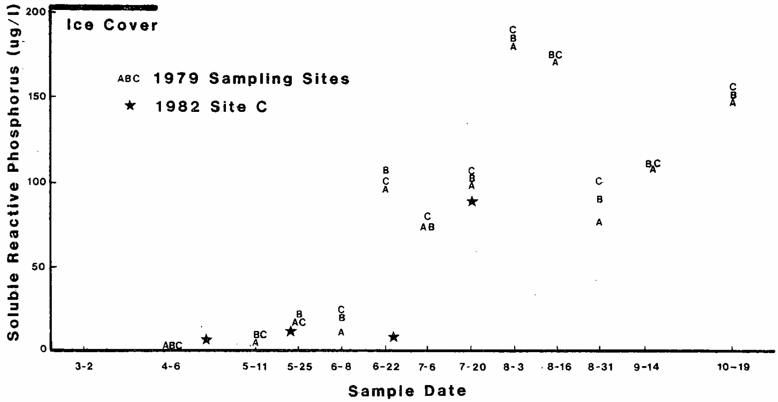


Figure 2-11. Averaged soluble reactive phosphorus concentrations for Cedar Lake sampling sites in 1979 and 1982.

TP and SRP values for 1982 appear to be slightly less than values recorded in 1979. Figure 2-12 shows a plot of total phosphorus concentrations minus SRP concentrations. This expression represents bound phosphorus. The difference between bound phosphorus and total phosphorus represents SRP. Figure 2-12 illustrates that SRP accounts for most of the increase in total phosphorus in Cedar Lake during the summer of 1979.

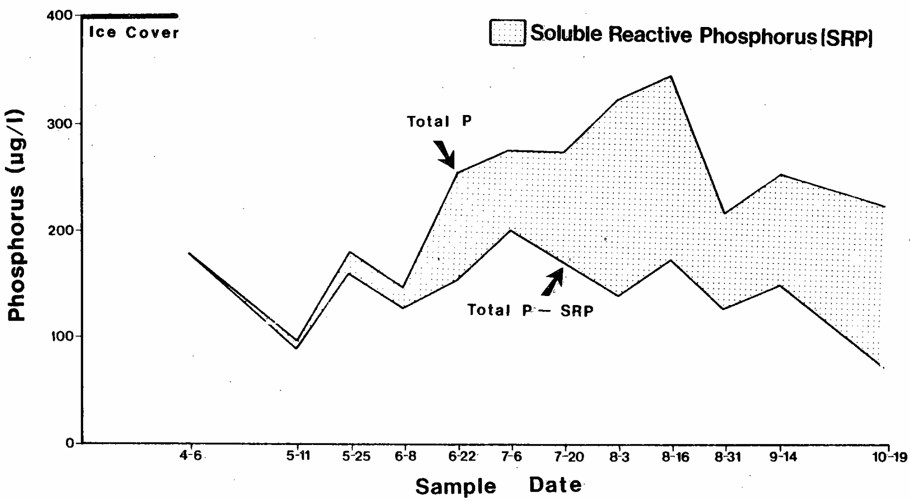


Figure 2-12. Fractionation of phosphorus in averaged samples for Cedar Lake in 1979.

2.2.4 Nitrogen

Nitrogen samples were acidified with H_2SO_4 in the field, stored on ice and refrigerated upon arrival at the laboratory. Within a week, total Kjeldahl nitrogen (TKN) samples were digested with a mercuric catalyst solution and total ammonia was then determined potentiometrically after basification. TKN results are expressed as the sum of free ammonia and organic nitrogen in mg/l. Ammonia and nitrate and nitrite analyses were performed on a Technicon Auto-analyser II. Because the kinetics of the conversion of nitrite to nitrate are very fast, nitrite concentrations are very low in the samples. For this reason, results are expressed only as NO_3-N and NH_3-N in mg/l.

The fractionations of nitrogen are reported (and determined) in various ways in published analyses. The terms used here are as followed:

Total Kjeldahl nitrogen (TKN)	= measured (See Appendix A)
Nitrate + nitrite (NO_3-N + NO_2-N)	= measured (See Appendix A)
Ammonia (NH_3-N)	= measured (See Appendix A)
Total nitrogen	= TKN + NO_3 + NO_2
Organic nitrogen	= TKN - NH_3
Inorganic nitrogen	= NO_3 + NO_2 + NH_3

Data for TKN, nitrate, and ammonia are presented in Figures 2-13, 2-14, and 2-15. TKN concentrations dropped slightly in late spring, rose during the summer, and started to decline in late summer. Ammonia concentrations followed this same pattern. Nitrate, on the other hand, dropped during the spring and early summer, and remained at or near zero for the remainder of the sampling period. TKN and ammonia concentrations in 1982 were within the range of values reported for 1979, although TKN values for 1982 were slightly lower.

The relationship between these nitrogen fractions is perhaps better illustrated in Figure 2-16. From this figure, it is seen that ammonia comprised the bulk of inorganic nitrogen and accounted for a large percentage of the rise in total nitrogen levels on August 16, 1979. Since ammonia is a normal biological degradation product of nitrogenous organic matter (U.S. Environmental Protection Agency 1976a) the peak observed on August 16 could be associated with a *Microcystis* algae die-off observed in mid-July (see Section 2.6.1) or with sediment release of ammonia under anaerobic conditions (Wetzel 1975).

2.2.5 Chlorophyll a

Chlorophyll *a* samples were collected in opaque polyethylene containers, stored on ice in the field, and refrigerated upon arrival at the lab. Samples were filtered within 48 hours. Filters were stored frozen in the dark and analyzed for chlorophyll *a* on a

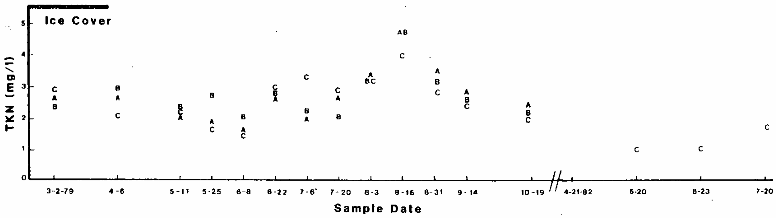


Figure 2-13. Averaged total Kjeldahl nitrogen values for Cedar Lake sample sites in 1979 and 1982.

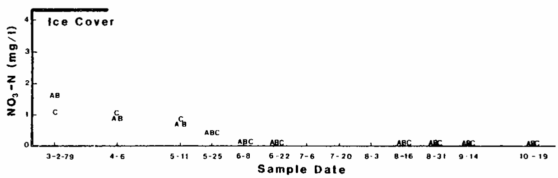


Figure 2-14. Averaged nitrate values for Cedar Lake sample sites in 1979. Missing data are due to analytical equipment failure.

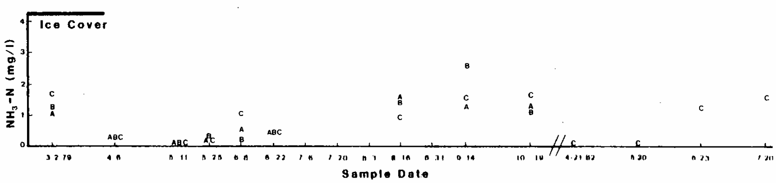


Figure 2-15. Averaged ammonia values for Cedar Lake sample sites in 1979 and 1982. Missing data are due to analytical equipment failure.

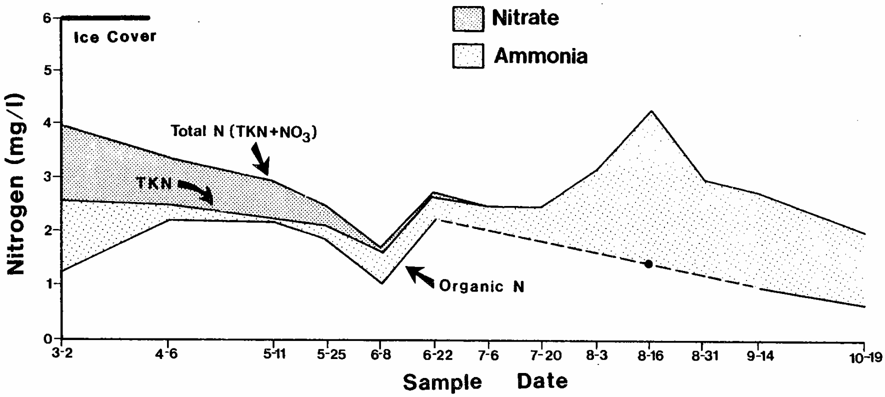


Figure 2-16. Fractionation of nitrogen in averaged samples for Cedar Lake in 1979.

spectrophotometer by the trichromatic method and corrected for pheophyton. A detailed description of analytical procedures used is presented in Appendix A.

Chlorophyll is the pigment found in all plants which is used in photosynthesis, and thus can be used as an indirect measure of the standing crop of photosynthetic organisms in a lake (Vollenweider 1968). This measurement is only an estimate because all species do not contain equivalent amounts of chlorophyll. The success of chlorophyll extraction can vary from species to species as well.

Chlorophyll a values for Cedar Lake are presented in Figure 2-17. Spring values were approximately 50 mg/m^3 was observed on July 6 and coincided with an observed Microcystis bloom. These concentrations indicate high productivity and trophic status when compared with other lakes that have been studied (Figure 2-18).

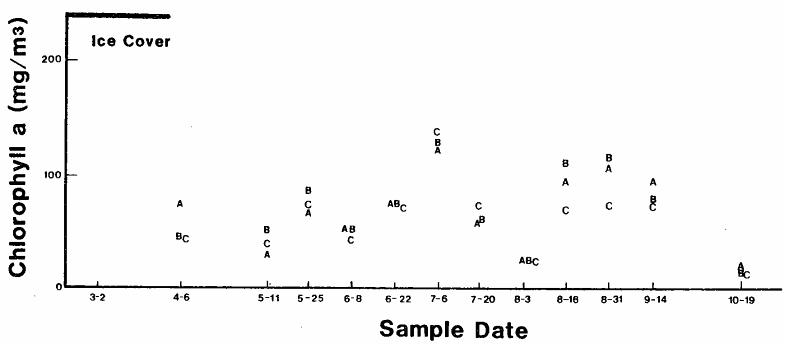


Figure 2-17. Average chlorophyll a concentrations for Cedar Lake sample sites in 1979.

Secchi disc and turbidity measurements from Cedar Lake (Figures 2-20 and 2-21) are very similar and indicate decreasing light penetration through the spring and summer. The maximum Secchi disc reading occurred on May 11 (58 cm.) and the minimum occurred on August 31 (22 cm.). With the exception of May 25 when extremely strong winds caused stirring of bottom sediments, the decreasing trend probably results from increasing phytoplankton density. Secchi disc transparencies in 1982 were similar to those measured during 1979.

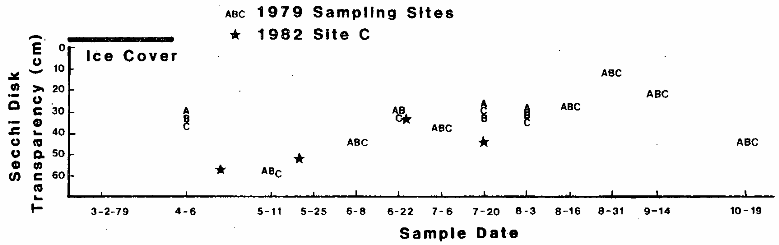


Figure 2-20. Secchi disc transparencies for Cedar Lake sample sites in 1979 and 1982.

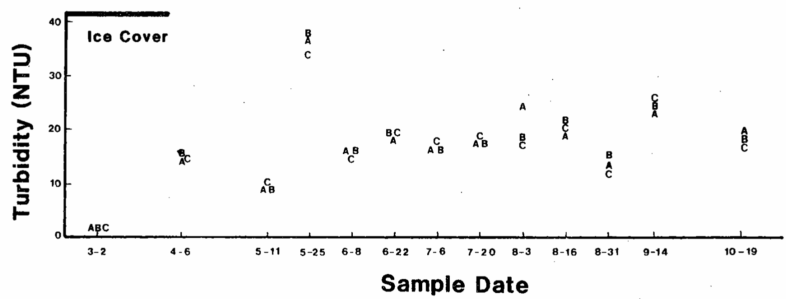


Figure 2-21. Averaged turbidity values for Cedar Lake sample sites in 1979.

2.2.7 Total Volatile and Fixed Residues

The fractions of total volatile residue (TVR) and total fixed residues (TFR) in water samples was determine for lake and stream sites on three sampling dates in 1982. Water samples were weighed, dried, and ashed at 550°C according to precedures described in Standard Methods (APHA 1981).

Total volatile residues in the lake samples range between 107 and 178 mg/l or 26 to 41 percent of total residue (Table 2-3). There is a slight tendency for TVR to increase during the spring into summer and this is consistant with increasing algal biomass during the same period. There is no obvious relationship between TVR and water depth.

Table 2-3. Total volatile and fixed residue for 1982 Cedar Lake water samples. Brackets ( ) represent percent of total residue.

Sample Site	Total Volatile Residue (mg.l)			Total Fixed Residue (mg/l)			Total Residue (mg/l)		
	4-21	5-20	6-24	4-21	5-20	6-24	4-21	5-20	6-24
C_1	107(26)	148(33)	158(37)	305(74)	300(67)	271(63)	412	448	429
C_2	128(32)	168(35)	178(41)	278(68)	317(65)	260(59)	406	485	438
C_3	123(32)	174(33)	153(35)	243(66)	358(61)	282(65)	366	532	435
D	118(30)	172(39)	200(33)	280(70)	268(61)	402(67)	398	440	602
E	156(34)	217(35)	182(35)	308(66)	396(65)	338(65)	464	613	520
F	161(29)	173(38)	-	387(71)	456(62)	-	548	629	-
G	117(32)	175(32)	-	247(68)	369(68)	-	364	544	-
H	93(26)	206(31)	169(32)	265(74)	457(69)	353(68)	358	663	522
J	108(32)	230(41)	106(38)	231(68)	328(59)	174(62)	339	558	280
k	213(31)	226(36)	220(31)	483(69)	407(64)	497(69)	696	633	717
L	214(37)	250(35)	-	364(63)	471(65)	-	578	721	-

Total fixed residues in the lake samples vary between 243 and 358 mg/l and may reflect variable resuspension of inorganic sediments by winds or motor boats. Total residues range between 366 and 532 mg/l for lake samples.

2.2.8 Fecal Coliform Bacteria

Fecal coliform bacteria are the normal inhabitants of the intestinal tract of all warm-blooded animals, including humans. They are therefore present in fecal matter and are numerous in domestic wastewater. Consequently, the presence of large numbers of fecal coliform bacteria in lake water is indicative of potential wastewater contamination.

Fecal coliform bacteria counts were measured by the Lake County Health Department at 10 sites around Cedar Lake (Figure 2-22). Data from June through September, 1979 are presented in Table 2-3. When compared to Indiana's Water quality standards of 200 fecal coliform bacteria per 100 ml for total body contact recreation, the 1979 values are within the standards except for a few isolated cases. The 1982 values are similar to those from 1979.

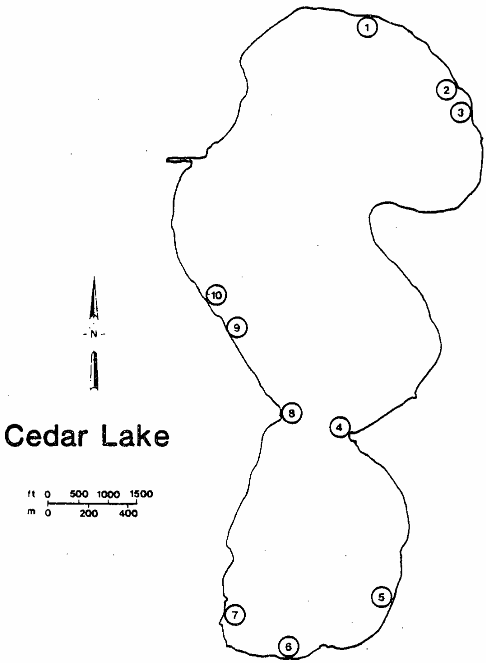


Figure 2-22. Sampling sites for fecal coliform bacteria in Cedar Lake.

2.2.9 Twenty-four Hour Survey

On August 21, 1979 we began a 24-hour duration survey of temperature, dissolved oxygen, pH, and conductivity at Site C (south basin) on Cedar Lake. Sampling began at 1200 hours on August 21 and continued at 4-hour intervals until 1200 hours on August 22. Determinations of the four parameters were made at one foot depth intervals from the surface to the bottom using methods described previously. The sample period was characterized by mostly cloudy skies and calm wind conditions. The results of the survey are presented in Figure 2-23.

Table 2-4. Fecal coliform bacteria colony counts for Cedar Lake sample sites in 1979 and 1982[1].

Date	Site 1	2	3	4	5	6	7	8	9	10
5-17-79	100	980	10	0	10	0	0	40	0	20
5-14-79	0	0	190	0	0	0	200	0	0	0
5-31-70	0	0	0	0	0	0	0	0	0	0
6-07-79	0	110	370	0	0	70	0	0	10	750
6-14-79	100	40	110	350	150	3000	30	0	0	160
6-21-79	50	70	450	0	20	0	90	0	20	50
6-28-79	0	10	260	0	0	0	10	20	10	0
7-05-79	10	10	0	0	0	0	0	x	0	0
7-12-79	30	30	30	0	0	30	0	10	0	20
7-19-79	0	20	0	10	0	0	10	0	0	20
7-26-79	40	790	20	10	210	30	0	10	50	280
8-02-79	30	10	70	0	10	20	0	0	40	100
8-16-79	0	0	0	0	0	0	10	10	0	0
8-23-79	10	40	50	20	10	20	30	40	20	40
8-30-79	0	0	0	0	20	70	20	20	0	10
9-06-79	0	10	20	10	0	0	0	0	10	30
9-13-79	80	0	0	0	0	0	120	0	0	90
9-20-79	80	60	0	0	0	10	20	560	140	320
6-03-82	10	100	60	0	10	10	20	20	70	0
6-10-82	20	10	200	110	10	0	0	50	20	70
6-17-82	10	10	0	0	0	0	0	20	0	10
6-24-82	0	0	0	0	0	0	0	10	0	0
7-01-82	0	0	0	0	10	0	0	0	0	0
7-08-82	0	0	0	0	0	0	0	0	0	0

[1]total counts per 100 ml/4-sample mean

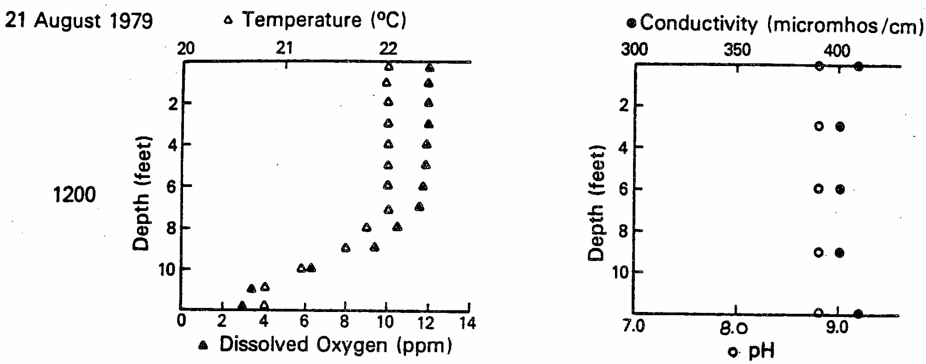
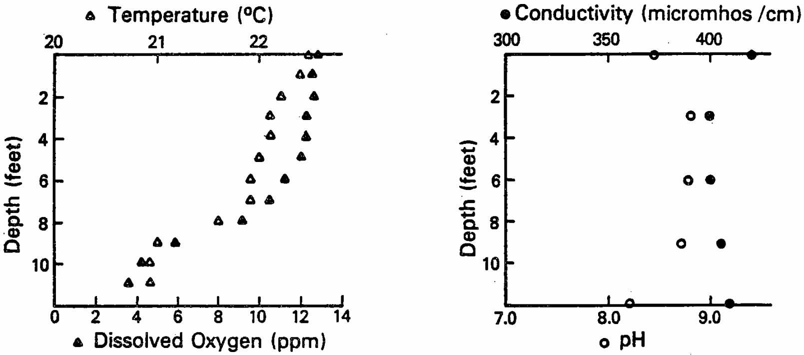
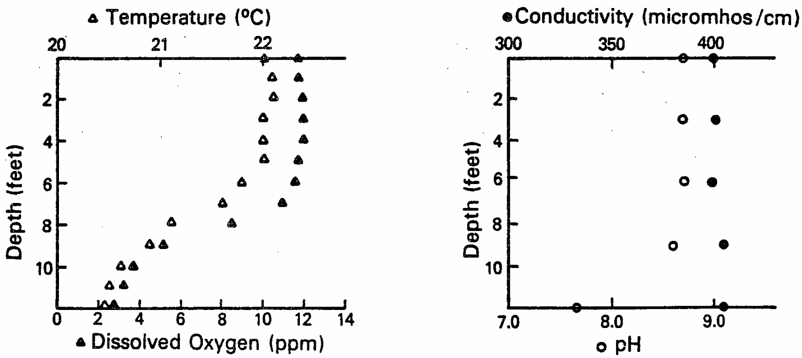


Figure 2-23. Twenty-four hour survey results.

1600



2000



21 August 1979

2400

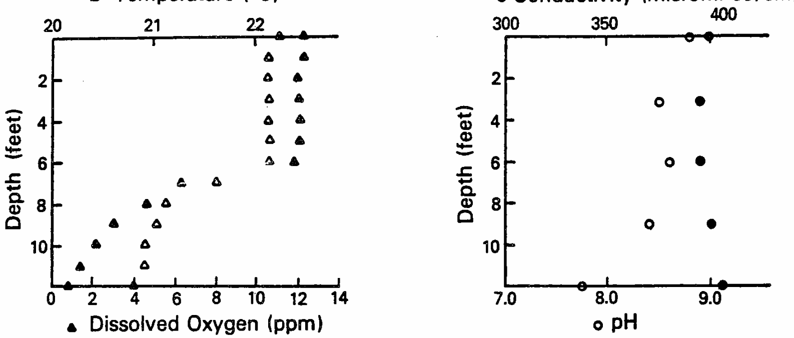


Figure 2-23 (continued)

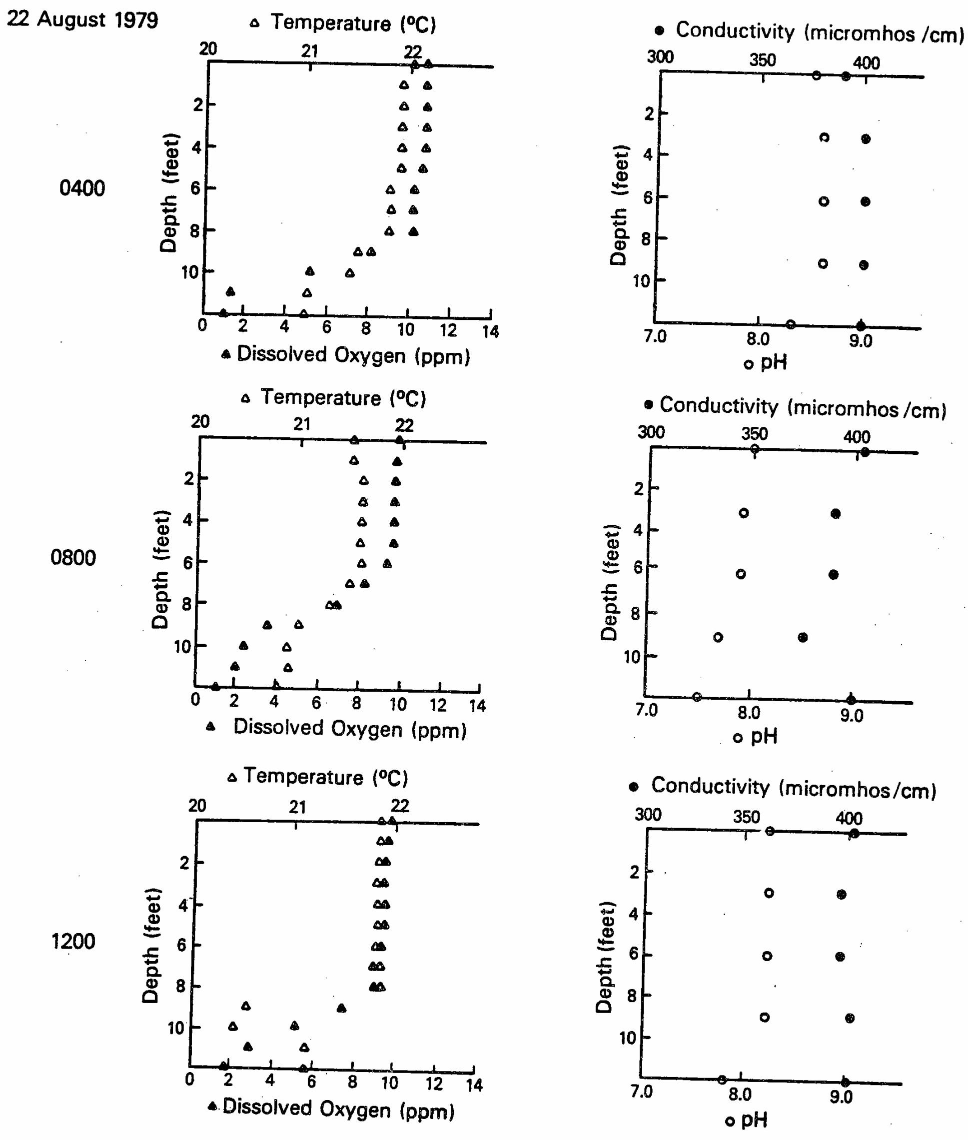


Figure 2-23 (continued)

Even though cloudy skies probably caused some reduction in photosynthetic activity within the lake, differences between daytime photosynthesis and night-time respiration are still apparent in the data. During the day, photosynthesis in the trophogenic zone results in increased dissolved oxygen concentrations and increased pH due to excessive photosynthetic utilization of CO_2 (Wetzel 1975). This process is reversed during the night.

After 1600 hours on August 21, both temperature and dissolved oxygen levels in the surface waters of Cedar Lake began to decline slightly according to this diurnal cycle. This trend continued throughout the night and into the next morning where at 1200 hours, surface water temperature began to rise again. Dissolved oxygen levels continued to slowly fall. pH declined throughout the 24-hour period possibly due to the reduction in photosynthesis caused by cloudy skies.

The calm wind conditions allowed the lake to temporarily stratify. A weak thermocline, as indicated by the temperature and dissolved oxygen curves, developed by 1200 hours beginning at a depth of seven feet. By 2400 hours it rose to six feet but was later pushed to approximately eight feet at 0400 hours as early morning winds deepened the mixing zone. The effects of temporary stratification can also be observed to a lesser extent in the pH values.

The temporary stratification also resulted in depleted oxygen levels below the weak thermocline. Dissolved oxygen dropped to a low of 1.4 ppm or 16% of saturation just off the bottom at 2400 hours. Concentrations this low will cause stress in most species of fish.

2.2.10 <u>Summary</u>

1. Cedar Lake has a polymictic circulatory pattern - no permanent summertime stratification was observed. Temporary stratification was observed during periods of calm winds. Dissolved oxygen concentrations were low in the deepest waters at the end of the winter and during calm wind conditions in the summer. This suggests that anoxic conditions may be present in the sediments.

2. Alkalinity, pH, and specific conductance values were moderate and indicate a hard water lake. pH values are higher in the summer than in the winter probably due to algal production.

3. Phosphorus and nitrogen data suggest that Cedar Lake is nitrogen limited. Soluble reactive phosphorus concentrations increase in the lake through the spring and summer until August when they represent more than 50% of total lake phosphorus. Nitrate levels decrease through the spring and remain near zero during the summer.

4. Chlorophyll <u>a</u> values for Cedar Lake, when compared with literature values, indicate a high biological production that is typically associated with eutrophic or hypereutrophic conditions.

5. Fecal coliform bacteria data collected by the Lake County Health Department during 1979 and 1982 show several isolated violations of Indiana's water quality standards for fecal coliform bacteria.

2.3 WATER QUALITY - STREAMS

All streams associated with Cedar Lake (Figure 2.1) were tested for water quality and algae when flowing. Water samples were collected directly in sample containers on the afternoon of sampling days and were stored and analyzed in the same way as lake samples (see Section 2.2). The inlet streams were sampled at Sites D, E, and F, from bridges on Lauerman Street, which parallels the southwestern shore of the lake. Streams D and E flow from Cedar Lake Marsh at the southern end of Cedar Lake and Stream F flows through agricultural and residential areas. Cedar Creek, the outlet stream (G), was sampled immediately downstream from the control structure. Two water channels (H,I) which never exhibited any flow, were sampled at locations next to the lake. Several additional sampling sites were sampled during 1982 to investigate changes in water quality in water flowing through Cedar Lake Marsh. Site J is located approximately 50 m (150 ft) into the wetland and Sites K and L were located on inlets to the western edge of the wetland.

Water chemistry data from Sites D, E, F, G, J, K, and L are presented within the text and in Appendix B. Data for streams H and I are included in Appendix B only. All of the reported data are in concentrations and do not accurately reflect loading to Cedar Lake (concentration x flow). In addition, since the inflowing strams to Cedar Lake are intermittent, they are characterized by increased temperatures, decreased dissolved oxygen levels, and the concentrating of nutrients as they dry up in the spring. These factors are relatively unimportant to the lake's water quality because of the limited flow.

2.3.1 <u>Temperature and Dissolved Oxygen</u>

Temperature characteristics of Cedar Lake and streams are presented in Table 2-5. Sites D and E were generally warmer than the lake, while stream F was usually cooler. Cedar Creek (G) was warmer than the center of the lake, due to shallow water levels on either side of the control structure that facilitate solar heating. 1982 was characterized by a warm spring and a cool summer.

Table 2-6 presents dissolved oxygen data for Cedar Lake and its associated streams. With the exception of high dissolved oxygen levels observed in early March, Site F had oxygen levels similar to those in the lake in the spring. The low concentrations in June, 1979 and May, 1982, resulted from decreased streamflow and somewhat stagnant conditions. Sites D and E were also similar in oxygen content to lake conditions, except on May 11, 1979, when very low dissolved oxygen (1-3 ppm) was recorded. All the streams and Cedar Lake Marsh (Site J) exhibit wide variations in saturation levels. Cedar Creek's oxygen levels were near saturation because of the high dissolved oxygen within Cedar Lake and the oxygenation which occurs as the water flows over the control structure.

Table 2-5. Spring temperature (°C) characteristics of Cedar Lake and its associated streams on selected dates in 1979 and 1982. (nf = no flow).

Date	Cedar Lake (range)	D	E	F	G	J	K	L
3-10-79	0.7- 3.8	1.0	1.0	1.0	-	-	-	-
4-06-79	4.1- 5.0	5.8	5.5	5.5	-	-	-	-
5-11-79	17-8-21.0	22.0	21.0	17.7	20.0	-	-	-
5-25-79	13.5-14.0	16.5	14.9	12.0	15.0	-	-	-
6-08-79	21.0-24.5	27.0	25.0	22.0	27.0	-	-	-
6-22-79	22.5-24.0	24.8	26.0	21.8	nf	-	-	-
3-22-82	ice	4.8	3.0	3.0	4.5	3.0	8.5	7.0
4-21-82	11.0-12.0	8.9	10.2	10.0	10.5	10.1	13.0	10.0
5-20-82	22.0	21.5	22.0	22.0	21.3	21.5	20.0	17.2
6-24-82	20.7-21.0	19.7	17.5	nf	nf	17.0	18.0	nf

Table 2-6. Dissolved oxygen concentrations (ppm/% saturation) for Cedar Lake and its associated streams on selected dates in 1979 and 1982 (nf = no flow).

Date	Cedar Lake (range)	D	E	F	G	J	K	L
3-10-79	2.4- 7.3/ 18- 51	5.8/ 41	5.0/ 35	11.0/ 77	-	-	-	-
4-06-79	13.9-14.2/107-111	12.1/ 97	13.4/106	13.0/103	-	-	-	-
5-11-79	8.2-13.2/ 87-150	3.1/ 36	1.0/ 11	7.3/ 78	11.4/127	-	-	-
5-25-79	8.6- 9.0/ 84- 87	10.5/108	8.0/ 80	9.8/ 91	9.3/ 93	-	-	-
6-08-79	5.4-12.0/ 61-145	5.4/ 68	6.4/ 78	5.0/ 57	8.0/101	-	-	-
6-22-79	5.1- 8.1/ 59 98	6.2/ 76	8.0/100	2.3/ 26	nf	-	-	-
3-22-82	ice	5.1/ 40	5.5/ 41	10.5/ 78	5.0/ 38	9.4/ 70	7.9/ 67	10.2/ 84
4-21-82	10.6-11.6/ 97- 98	4.2/ 36	10.2/ 90	12.9/114	10.7/ 96	8.5/ 75	9.0/ 85	11.0/ 97
5-20-82	8.8- 9.1/100-103	7.3/ 82	4.3/ 49	1.2/ 13	7.7/ 86	6.3/ 71	3.1/ 34	5.3/ 55
6-24-82	9.5-11.0/109-121	5.8/ 63	1.8/ 19	nf	nf	3.8/ 39	1.0/ 11	nf

2.3.2 Alkalinity, Conductivity, and pH

Alkalinity, specific conductance, and pH measurements from Cedar Lake and its streams are presented in Tables 2-7 - 2-9. Alkalinity and conductivity values increased through the spring until late May - early June, 1979, after which they decreased. The conductivity at Site F was considerably higher than Cedar Lake. The pH of the streams were slightly alkaline. The variations of pH that occurred in Site D may have been due to the high productivity that was observed in this wetland-stream area.

Table 2-7. Alkalinity data (mg/l $CaCO_3$) for Cedar Lake and its associated streams on selected dates in 1979.

Date	Cedar Lake (range)	Inflowing Streams D	E	F	Outflowing Stream G
3-10	126-175	33	47	62	-
4-6	111-133	74	97	149	-
5-11	102-110	115	134	144	109
5-25	117-128	116	168	193	120
6-8	117-133	144	147	220	150
6-22	119-127	107	123	108	Dry Bed

Table 2-8. Specific conductance (umhos/cm) of Cedar Lake and its associated streams on selected dates in 1979.

Date	Cedar Lake (range)	Inflowing Streams D	E	F	Outflowing Stream G
3-10	370-500	160	260	290	-
4-6	370-385	300	450	570	-
5-11	340-360	310	450	670	360
5-25	360-370	380	450	720	360
6-8	380-400	340	380	740	400
6-22	370-400	290	370	290	Dry bed

Table 2-9. pH values for Cedar Lake and its associated streams on selected dates in 1979 and 1982 (nf = no flow).

Date	Cedar Lake (range)	D	E	F	G	J	K	L
3-10-79	6.5-6.6	6.5	6.7	5.8	-	-	-	-
4-06-79	8.0-8.2	7.5	7.4	7.7	-	-	-	-
5-11-79	8.5-9.2	7.2	7.3	7.6	8.6	-	-	-
5-25-79	8.1-8.5	8.9	7.5	7.5	8.5	-	-	-
6-08-79	7.3-8.5	7.0	7.7	7.7	7.7	-	-	-
6-22-79	7.5-8.1	9.3	8.4	7.2	nf	-	-	-
3-22-82	ice	6.5	6.7	6.8	6.7	6.4	7.3	7.2
4-21-82	8.2-8.4	6.8	7.1	7.4	8.4	7.1	7.8	7.2
5-20-82	8.1	7.2	6.9	6.9	7.9	6.7	7.2	7.2
6-24-82	7.6	7.4	6.9	nf	nf	6.8	7.0	nf

2.3.3 Phosphorus

Table 2-10 presents concentrations of soluble reactive phosphorus (SRP) and total phosphorus (TP) levels in Cedar Lake and its associated streams during the spring of 1979 and 1982. Elevated total phosphorus levels in the inlet streams occurred on March 10, which is not uncommon during the period of snowmelt. High total phosphorus concentrations later in the spring probably resulted from the concentrating effect when streamflows were reduced. A high ratio of SRP to total phosphorus was observed in all streams. The input of available phosphorus into Cedar Lake during the spring could stimulate early algal production if the lake was phosphorus limited at that time. However, total loading from the streams was estimated to be low due to limited discharge. The wetland Site (J) had high phosphorus levels, as expected, due to standing water. Sites K and L, which drain agricultural fields, had higher phosphorus concentrations than inlet streams at Sites D and F.

Table 2-10. Phosphorus concentrations (SRP/Total P) for Cedar Lake and its associated streams on selected dates in 1979 and 1982 (nf = no flow). Units are ug/l.

Date	Cedar Lake (range)	D	E	F	G	J	K	L
3-10-79	- - -/115-175	129/198	305/390	140/210	-	-	-	-
4-06-79	1 - 3/157-224	60/165	- /149	- / 85	-	-	-	-
5-11-79	5 - 11/ 71-143	58/205	132/211	90/191	7/ 96	-	-	-
5-25-79	18- 24/155-107	16/163	40/ 71	80/114	19/202	-	-	-
6-08-79	11- 24/138/154	71/188	118/380	367/740	42/531	-	-	-
6-22-79	94-122/238/286	82/302	84/280	352/438	nf	-	-	-
4-21-82	8/ 93	26/125	103/164	52/100	3/ 400	25/184	79/156	52/ 80
5-20-82	10/190	7/268	275/490	157/266	10/126	355/922	-/634	195/297
6-24-82	8/176	49/388	93/532	nf	nf	495/812	172/204	nf

2.3.4 Nitrogen

Table 2-11 presents nitrate plus nitrite, ammonia, and total Kjeldahl nitrogen (TKN) concentrations in Cedar Lake and its streams. Nitrate levels in the streams was quite high in the spring, particularly in Sites E and F, and subsequently declined to near zero by early June. Ammonia levels followed an opposite trend; higher levels were observed in early June. Total nitrogen (TKN + nitrate + nitrite) inputs from streams into Cedar Lake were highest in early spring, and were primarily present as nitrates.

Table 2-11. Nitrogen concentrations (nitrate + nitrite/ammonia/TKN for Cedar Lake and its associated streams on selected dates in 1979. Units are mg/l (nf = no flow).

Date	Cedar Lake (range)	D	D	F	G
3-10-79	0.7-2.6/0.9-1.9/1.6-3.7	- / - /1.8	- / - /2.9	- / - /1.7	-
4-06-79	0.8-1.1/0.3-0.4/1.7-3.0	2.1/0.1/2.0	10.6/0.2/1.4	8.6/0.1/0.5	-
5-11-79	0.6-0.7/0.0-0.1/1.9-2.7	0.0/0.1/2.3	0.6/0.2/2.3	6.2/0.1/1.8	0.7/0.0/2.3
5-25-79	0.4-0.5/0.1-0.3/1.0-3.1	0.4/0.1/3.1	0.0/0.1/1.5	0.8.0.3/1.3	0.4/0.2/3.6
6-08-79	0.1/0.0-1.7/1.2-2.2	0.9/1.1/2.0	0.1/0.8/0.9	0.1/2.1/1.9	0.1/2.1/3.2
6-22-79	0.0-0.1/0.4-0.6/2.0-3.2	0.1/1.0/4.3	0.1/1.1/4.5	0.3/0.6/2.0	nf

2.3.5 Summary

The streams flowing into Cedar Lake exhibit a wide range for the parameters measured. However, most of the values recorded were within the range determined for Cedar Lake, except when reduced flow created stagnant conditions in the streams. Nevertheless, total loadings of nutrients to Cedar Lake are probably quite low due to intermittent streamflows (see Chapter 3).

2.4 PRECIPITATION

Bulk precipitation (wetfall and dryfall) was collected in the field at two locations (Figure 2-1). Samples were collected in acid-washed, 500 ml glass bottles to which a 10.8 cm diameter glass funnel was attached. A three-pound coffee can with removable plastic liners was also used at one site for comparison. Both types of collection vessels yielded comparable results. The collection vessels were placed atop two meter poles which had been driven into the ground along the lakeshore. Samples were collected weekly and stored at 4°C until analyzed. Analysis for total phosphorus was conducted using the same method as for lake water.

The accurate determination of phosphorus concentrations in precipitation was made difficult by the inability to maintain adequate quality control at the sample sites. On several occasions, the combination of low rainfall and high evaporation left an insufficient volume of sample in the collection vessels. Some samples were contaminated with leaves, grass clippings, and other macro-organic matter. An attempt was made to prevent this contamination by placing nylon mesh screens over the collection vessels.

Results of precipitation analyses are presented in Table 2.12. The mean phosphorus concentration, as measured, was 52 ug/l. Phosphorus concentrations tended to vary with the volume of precipitation collected. Values for periods of low precipitaton were noticeably more concentrated. This was probably due to either greater relative evaporaton for low sample volumes or to phosphorus being scavenged from the atmosphere during the first momemts of rainfall event. Subsequent rainfall during a longer event is then less concentrated in phosphorus.

Table 2-12. Bulk precipitation (wetfall and dryfall) measured at two sample sites at Cedar Lake in 1979.

Sample Period	Total Volume (ml) (2 stations)	Mean Total P (ug/l)	Total Mass Loading (ug P)
4-27 to 5-11	139	89.8	12.5
5-11 to 5-18	93	156.2	14.5
5-18 to 5-25	Insufficient Sample		
5-25 to 6- 1	247	96.7	23.9
6- 1 to 6- 8	200	133.2	26.6
6- 8 to 6-15	Sample Contamination		
6-15 to 6-22	Sample Contamination		
6-22 to 6-29	Insufficient Sample		
6-29 to 7- 6	140	81.0	11.3
7- 6 to 7-13	Insufficient Sample		
7-13 to 7-20	Insufficient Sample		
7-20 to 7-27	260	33.0	8.6
7-27 to 8- 3	1,000	28.0	28.0
8- 3 to 8-17*	857	30.0	27.7
8-17 to 8-31*	Sample Contamination		
		x = 52 ug/l	x = 20 ug/wk

*two-week interval

Several authors have reported that winter loadings of phosphorus from the atmosphere to lakes can be significant, particularly if dry fallout is included (Barica and Armstrong 1971; Kluesener 1972). For this reason, the average weekly loading of phosphorus from the atmosphere to Cedar Lake, as measured, was applied over the entire year to calculate the mean annual areal loading rate as follows:

$$\frac{20\ \text{ug/wk}}{182\ \text{cm}^2\ \text{(total collection area)}} \times 52\ \frac{\text{wk}}{\text{yr}} \times \frac{1\ \text{g}}{10^6\ \text{ug}} \times \frac{10^4\ \text{cm}^2}{\text{m}^2}$$

$= 0.57\ \text{g/m}^2\text{/yr}$ or $5.7 \times 10^{-5}\ \text{kg/m}^2\text{/yr}$

Total annual mass loading of phosphorus from precipitation to Cedar Lake was then calculated by the following:

Total annual mass loading = annual areal loading x lake surface area

$= 5.7 \times 10^{-5}\ \text{kg/m}^2\text{/yr} \times 3.16 \times 10^6 \text{m}^2$

$= 180$ kg/yr

These calculated values represent our best estimates for Cedar Lake and fall within ranges reported by Wetzel (1975). Wetzel reports that the phosphorus content of precipitation can vary greatly - from 30 ug/l in nonpopulated regions over land, to well over 100,000 ug/l in the environs of urban-industrial aggregations. Areal phosphorus loadings from the atmosphere can range between 0.01 to 0.1 $\text{g/m}^2\text{/yr}$. For lakes in the Great Lakes Region, Pecor et al. (1973) reported a mean annual total phosphorus concentration of 27 ug/l in precipitaton over Houghton Lake, Michigan and Kluesener (1972) reported a mean annual total phosphorus concentration in precipitation over Lake Wingra, Wisconsin of 32 ug/l. Annual phosphorus loadings from precipitation at Lakes Houghton and Wingra were reported to be 0.15 $\text{g/m}^2\text{/yr}$ and 0.20 $\text{g/m}^2\text{/yr}$ respectively.

2.5 SEDIMENTS

The bottom sediments in Cedar Lake were perceived to be an important element early in the project period. For this reason, the analysis of the sediments was undertaken in several steps: (1) the depth of sediments was determined, (2) sediment cores were extracted and analyzed, (3) the release of nutrients from the sediments was determined using an elutriate test and laboratory column experiments, and (4) the distribution of surficial sediment textures was characterized from summer grab samples.

Summer grab samples of sediments, as well as samples of water and fish, were also analyzed for the presence of PCB's. Results are presented in Appendix C.

2.5.1 Depth of Sediments

The depth of sediments within Cedar Lake was determined during the winter while ice covered the lake. Six transects were run in a network with sample locations every 200 meters. At each location a six-inch diameter hole was bored through the ice with an ice auger through which a weighted disc was lowered to record the water depth. Sections of 5/8 inch diameter shafting rods were joined together and pushed through the sediments until bowing prevented further progress. This depth was assumed to be the original glacial till lake bed. Water depth was then subtracted from the depth to the original lake bed to yield the depth of sediment.

Figure 2-24 shows the depth of sediment at each of the sampling points. Note that the depth of sediments was quite variable throughout the lake. At several sampling sites in deeper water, only very shallow sediment depths were found. This could be accounted for by either very irregular deposition of glacial till material, or by the presence of impenetrable lenses or objects within the sediments.

From Figure 2-24, the total volume of sediments within Cedar Lake was calculated to be 6.7 million cubic meters. Care should be used in interpreting this number and the exact positioning of contour lines due to the small number of data points. A more exhaustive set of sampling points would yield a more accurate sediment depth contour map.

2.5.2 Sediment Core Analysis

After evaluating the depth of sediment data, several sediment cores were extracted from Cedar Lake in early March, 1979 at the locations noted in Figure 2-1. Sediment samples were obtained from the sites with a piston corer sampler. Coring was initiated about 10 cm above the sediment-water interface, and continued into the sediments for one meter. The core was then extracted and the coring tubes were sealed at both ends and stored in a vertical position. Coring proceeded in this way until the desired core depth was extracted for each site.

At Site 1, which was located over the deepest sediments, a core totalling 5.5 meters in depth was taken. One to two meter cores were taken from the other sites.

The sediment cores were extracted from the coring tubes after returning to the laboratory, wrapped in plastic and then in foil, and stored at 2°C. Cores 1, 2, and 5 were subsampled by taking a two cm slice at the desired depth. Several two cubic centimeter plugs were then taken from the middle of the slice. The plugs were analyzed for pollen, total phosphorus, total nitrogen, percent organic matter, particle size distribution, and metals.

Pollen Analysis. Pollen analyses of sediment cores extracted from Coring Sites 1 and 5 were undertaken to estimate the sedimentation rate in Cedar Lake from the pollen record. Each core was analyzed at various depths to determine the percentage of *Ambrosia* (ragweed) pollen relative to other species. The depth in the sediments at which the frequency of *Ambrosia* pollen rises sharply is accepted as the stratigraphic marker for land clearance and settlement in the midwest (Davis et al. 1973). The period usually associated with the *Ambrosia* rise in northern Indiana is the 1820's or approximately 150 years ago (Bailey 1972).

Pollen diagrams for sediment Cores 1 and 5 are presented in Figure 2-25. The pollen sequence in these profiles corresponds well with those from other studies in the midwest, suggesting that the vegetational changes in this area were under regional climatic control (Bailey 1972).

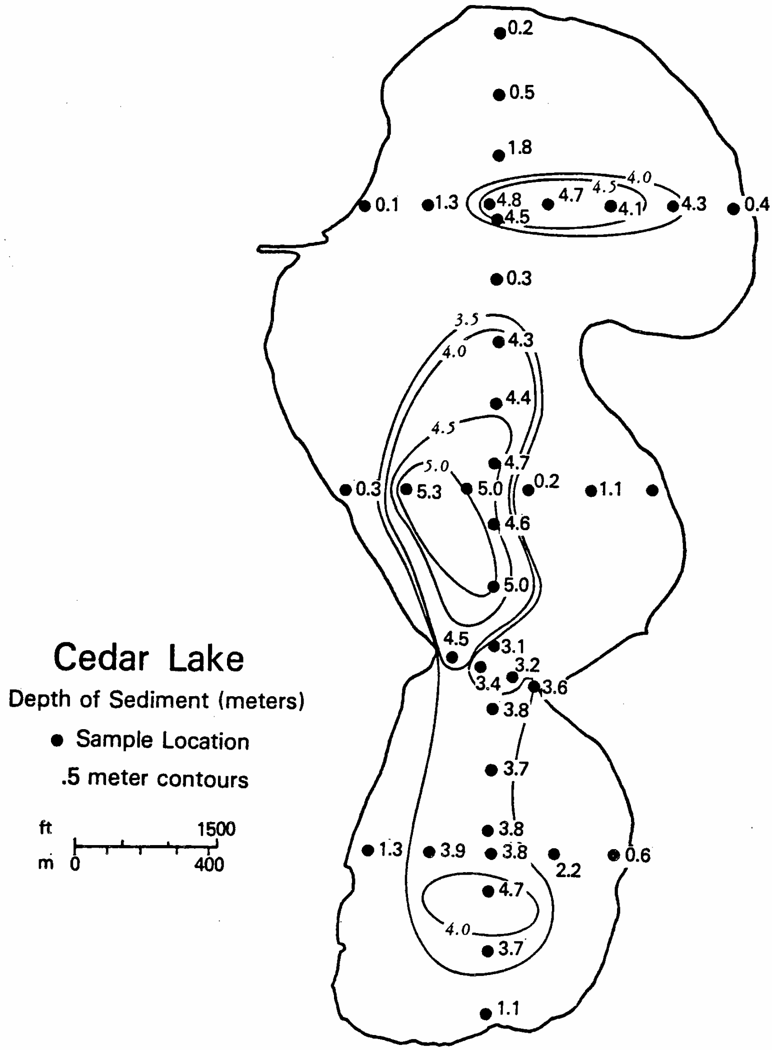


Figure 2-24. Depth of Cedar Lake sediments measured in 1979.

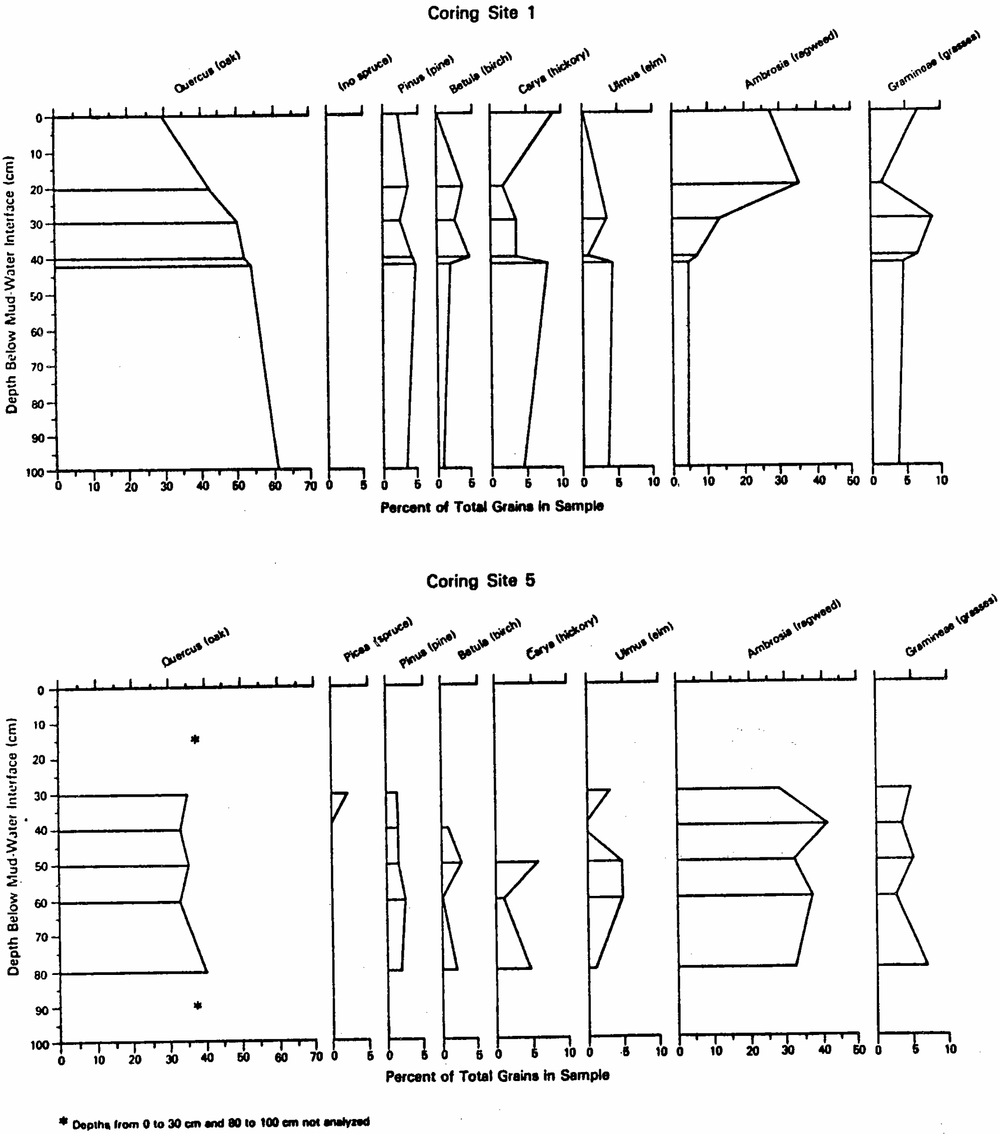


Figure 2-25. Pollen stratigraphy for Sediment Cores 1 and 5 from Cedar Lake.

The Ambrosia rise in Cedar Lake sediments begins at approximately 40 centemeters in Core 1 and somewhere below 80 centimeters in Core 5. This yields average sedimentation rates, since the 1820's, of 0.26 cm/yr for Core 1 and 0.53 cm/yr for core 5. These rates correspond with recent sedimentation rates calculated for Hudson (0.50 cm/yr) and Clear (0.73 cm/yr) Lakes in LaPorte County, Indiana (Bailey 1972).

The greater sedimentation rate estimated for Core 5 probably reflects greater erosional input to the south basin of Cedar Lake, from the inlet streams located in that basin. The middle basin has not had direct input from streams since the lake was lowered in the 1870's.

Phosphorus. Sediment subsamples from the cores were freeze-dried and digested in a sulfuric acid mercuric oxide potassium sulfate solution for total phosphorus. Digested samples were then diluted and analyzed colorimetrically on a Technicon Autoanalyzer II. A detailed description of analytical procedures used is presented in Appendix A.

Total phosphorus concentrations for sediment cores extracted from Coring Sites 1, 2, and 5 (Figure 2-1) are presented in Figure 2-26. Maximum concentrations were found in the upper 20 centimeters of sediment. Total phosphorus levels in this depth interval for the three cores ranged between 712 and 1067 mg/kg (parts per million) dry weight. Below 20 centimeters the concentration of phosphorus decreased rapidly as depth of sediment increased, and then stabilized at concentrations between 300 to 500 mg/kg below 80 cm.

The importance of phosphorus concentrations in sediments has been expressed by many authors. Under reducing conditions where phosphorus is released from sediments into the overlying water, the release mechanism has been treated as a diffusive process. The amount of phosphorus released is, in part, a function of the phosphorus content in the sediment (Ryding and Forsberg, 1977).

Few reported values are available for phosphorus in hypereutrophic lake sediments. However, values reported in the literature for some hypereutrophic lakes seem to be higher than those measured for Cedar Lake. Theis (1978) reports phosphorus levels in the upper 3 cm for two northern Indiana lakes to be 3420 mg/kg (dry weight) and 2280 mg/kg (dry weight). Data presented by Manny et al. (1978), give total phosphorus concentrations of approximately 6000 mg/kg.

However, pool values for phosphorus are not as important to the process of release as are dynamic properties such as the interactions of iron and phosphorus, which often define the fraction of phosphorus available for release to the overlying water. In this respect, the concentration of phosphorus in Cedar Lake sediments may be high enough for release processes to occur (Theis, personal communication).

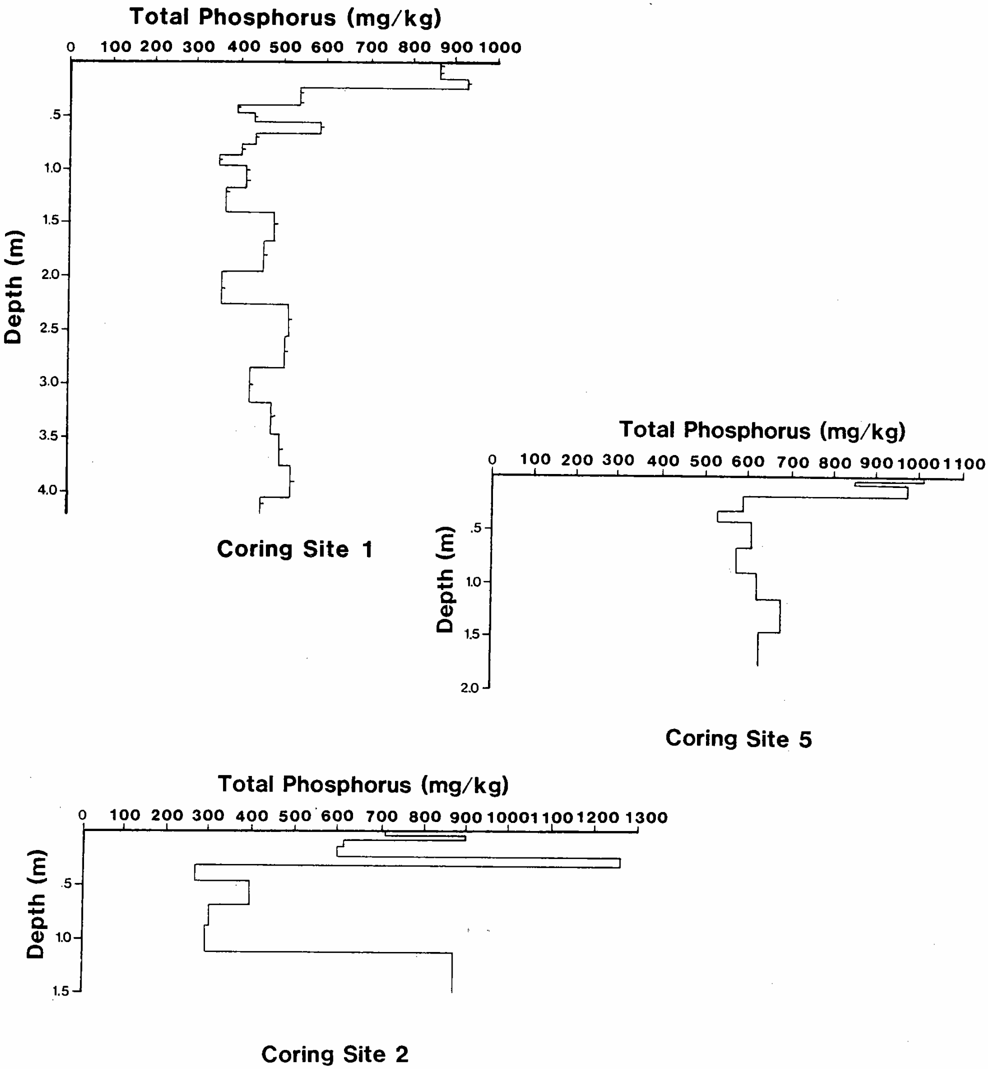


Figure 2-26. Total phosphorus concentrations in sediment cores from Cedar Lake in 1979.

Nitrogen. Sediment samples for nitrogen determination were also analyzed on a Technicon Autoanalyzer II. Unlike phosphorus, nitrogen concentrations did not appear to show a noticeable decline with increased depth (Figure 2-27). Inspection of Figure 2-27 shows concentrations of nitrogen in the upper 20 cm of the Site 1 sediment core to be around 11,000 mg/kg. As depth increases, concentrations decrease to 6000 mg/kg at 100 cm, then rise again before decreasing to 2000 mg/kg at 4 m.

Wide fluctuations in nitrogen concentration were evident in all cores analyzed. The level of nitrogen seems to be a function of the amount of organic matter at a particular depth. Depths with high nitrogen content were also high in organic matter. A positive correlation between nitrogen and organic matter has been reported by Wetzel and Manny (1978). A plot of nitrogen against percent organic matter for Cedar Lake sediments also shows a general positive relationship (Figure 2-28).

Lakes are relatively rich in nitrogen since nitrogen inputs as organic matter occur at relatively high rates. Thus, cultural inputs of nitrogen, such as septic and sewage effluents, do not necessarily contribute significantly more nitrogen to the system. For Marsh Lake, a eutrophic lake in northern Indiana, inputs of nitrogen as sewage accounted for only 22% of the total nitrogen input (U.S. Environmental Protection Agency 1976b). For Bass Lake, another eutrophic lake in northern Indiana that received septic tank loadings, only 22.5% of the total nitrogen loading was from sewage (U.S. Environmental Protection Agency 1976c).

Because nitrogen is closely associated with organic matter, nitrogen concentrations are expected to decrease on a per gram basis (dry weight) as the level of nonorganic sediments increases through sediment runoff. Phosphorus, on the other hand, enters a lake primarily in inorganic form. At Cedar Lake, the type of loading, along with denitrification processes, probably account for the lack of a more definitive peak in total nitrogen concentration in the upper layers of the sediment cores examined.

Percent Organic Matter. Samples of sediment from Sites 1, 2, and 5 were analyzed for percent organic matter by weight loss following ashing as 550°C. Samples were oven dried in porcelain crucibles to determine percent water, weighed on an analytic balance, then ashed in a muffle furnace for three hours and reweighed. A more detailed description of analytical procedures used is presented in Appendix A.

Organic matter is represented as the weight of material combusted at 550°C. This fraction of sediment is approximately equal to the total amount of organic material, such as detritus. No distinction was made between the particular types of organic material present.

Figure 2-29 illustrates the relationsip between percent organic matter and sediment depth for sediment cores 1, 2, and 5. The core from Site 1 has a bimodal distribution of organic matter with maximum amounts occurring between 25 and 60 centimeters and between

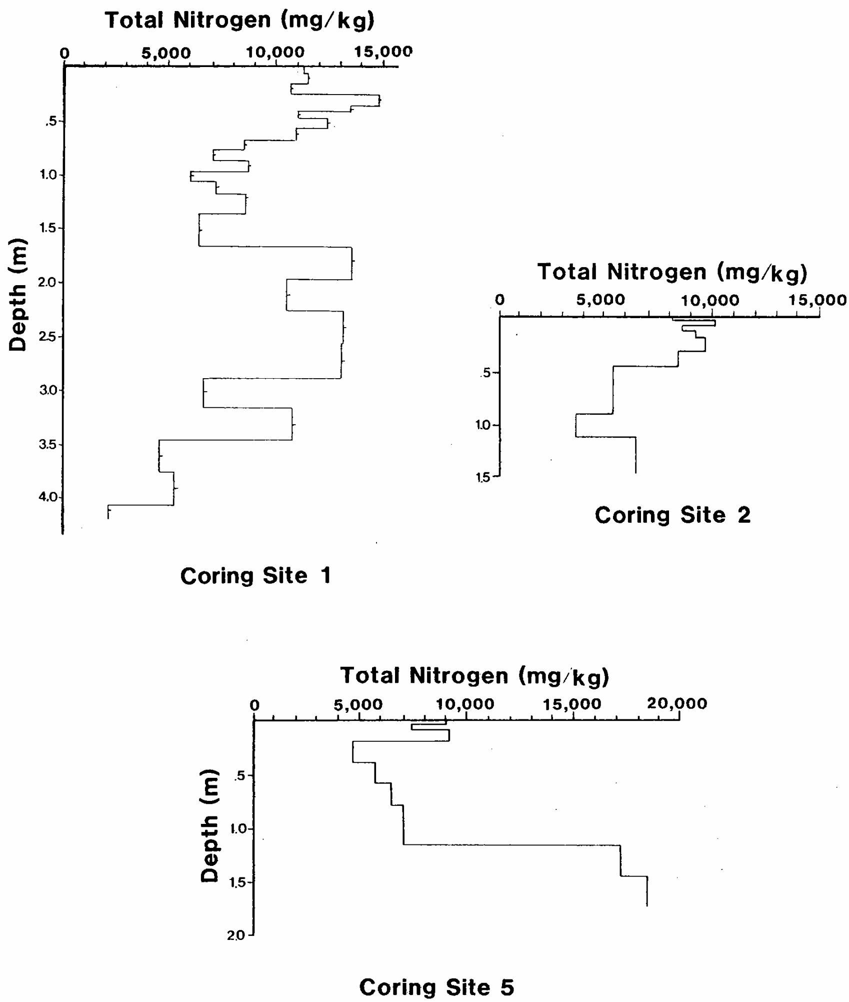


Figure 2-27. Total nitrogen concentrations in sediment cores from Cedar Lake in 1979.

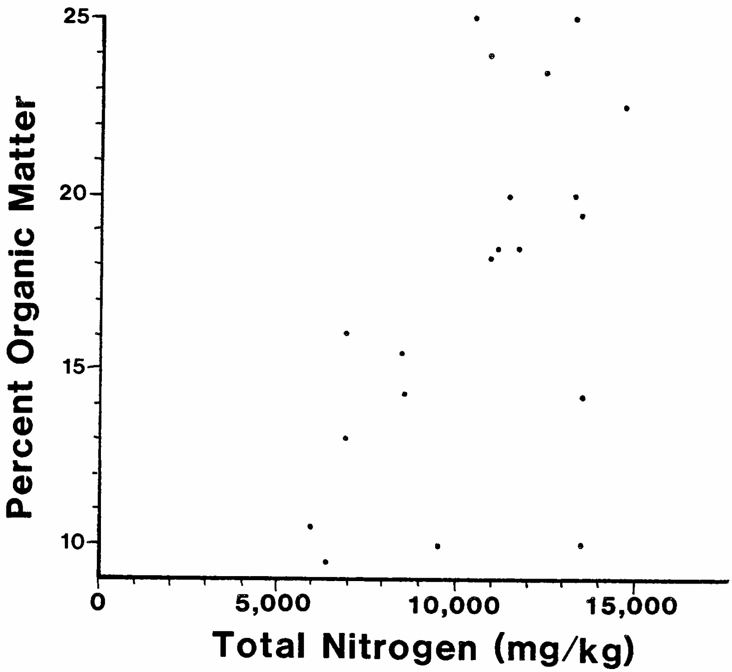
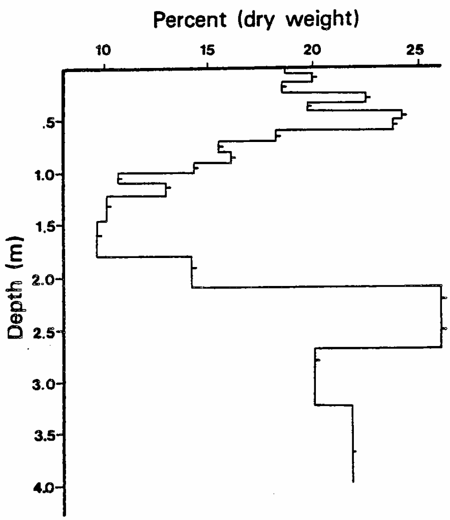
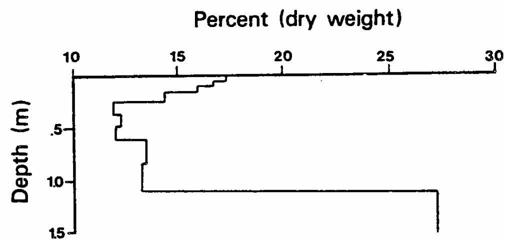


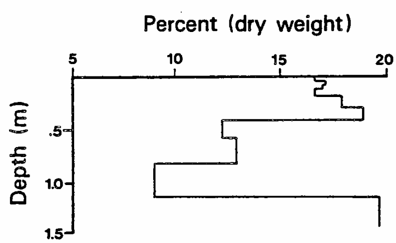
Figure 2-28. Correlation between percent organic matter and total nitrogen in Cedar Lake sediments.



Coring Site 1



Coring Site 2



Coring Site 5

Figure 2-29. Percent organic matter in sediment cores from Cedar Lake in 1979.

210 and 270 centimeters. In the upper 110 centimeters of sediment, the organic content ranged from roughly 10.6% to 24.2%.

The upper layers of sediment from Site 1 contained a higher percentage of organic matter than did sediments analyzed from Sites 2 and 5. The accumulation of organic matter at Site 1 may have been the result of post-depositional downslope movement of sediment along steep lake bottom gradients in the middle basin of Cedar Lake. Hargrave and Kamp-Nielsen (1977) remark that turbulence in the shallow littoral zone of lakes may cause erosion and subsequent transport of material to deeper, more quiescent areas.

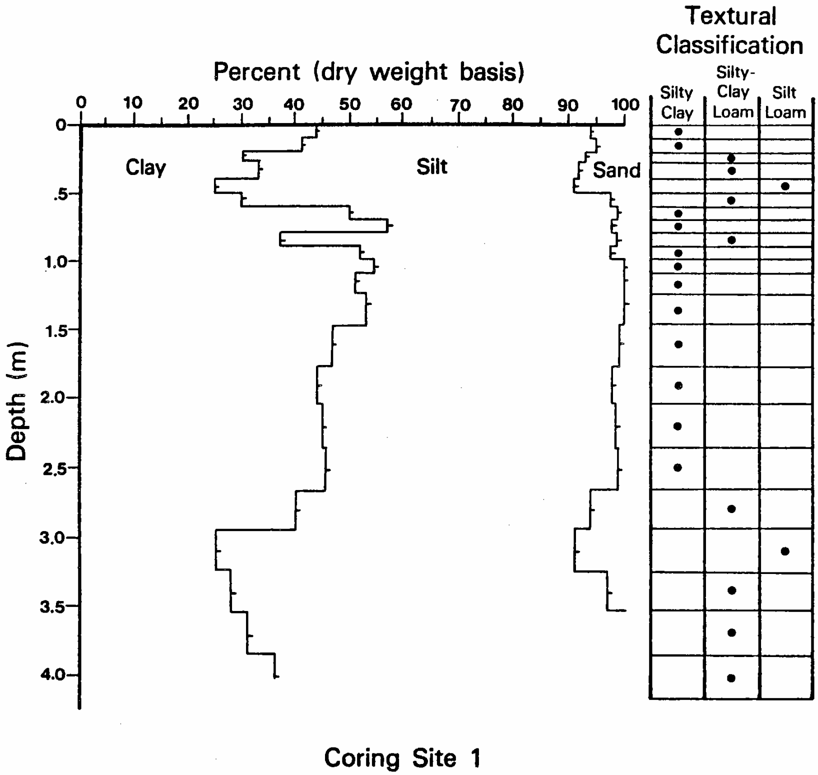
Surface sediments analyzed from Coring Sites 2 and 5 contain a lower percentage of organic matter when compared to the Site 1 sediment core. Both Cores 1 and 5 exhibited an increase in organic matter at a depth of 130 centimeters where the highest percentages occur. Organic matter content in the upper 110 centimeters ranged from 12.8% to 17.3% in sediment Core 1 and 9.2% to 19.2% in Core 5.

Because of the association between organic matter and nitrogen, the elevated levels of organic matter in the upper layers of Cedar Lake sediments constitute a reservoir of nitrogen that could potentially be released to the overlying water column under turbulent conditions. Under conditions similar to those in Cedar Lake, Ryding and Forsberg (1977) observed an increase in ammonia concentrations in Swedish lakes when winds were blowing lengthwise along the lakes. The increases were due to resuspension of nitrogen-enriched organic matter from the sediments.

Particle Size. Particle size distributions in sediment cores from Sites 1, 2, and 5 were determined using the pipette method described by Black (1965). This is a sedimentation procedure which utilized pipette sampling at controlled depths and times. The method is considered to be more accurate than the Bouyoucos hydrometer method (Black 1965). It must be noted that the method used in this analysis only applies to the inorganic particles in the sediment.

Figure 2-30 presents the fractionization of various particle size in sediments sampled from all three coring sites, accompanied by a standard U.S. Soil Convervation Service textural classification for each sampling depth. All core sections from the three sites were composed entirely of fine-grained sediments (more than half the total sample passed through a No. 40 sieve), with high proportions of silt and clay.

Particle sizes in cores from Sites 1 and 2 were fairly equally divided between clay and silt, however slight variations in the relative contribution of these two fractions exist. In Core 1, which was analyzed most thoroughly, there was a biomodal distribution of coarser sediments with peaks between 20 and 60 centimeters and between 295 and 330 centimeters. Particle sizes in Core 5 were compositionally skewed towards higher silt percentages, possibly due to the proximity of the inlet streams. Where sand did occur in the sediments, it rarely exceeded ten percent of the total.



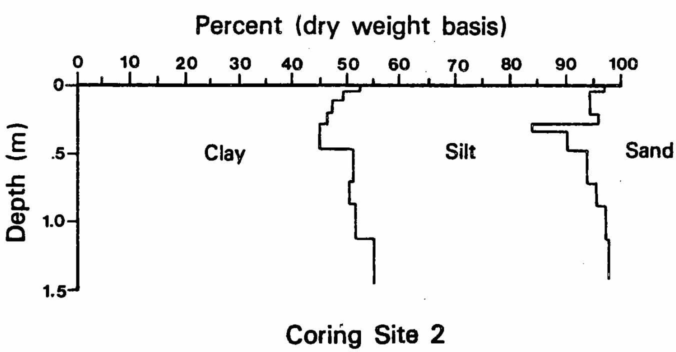


Figure 2-30. Inorganic composition of Cedar Lake sediments from Cores 1, 2, and 5.

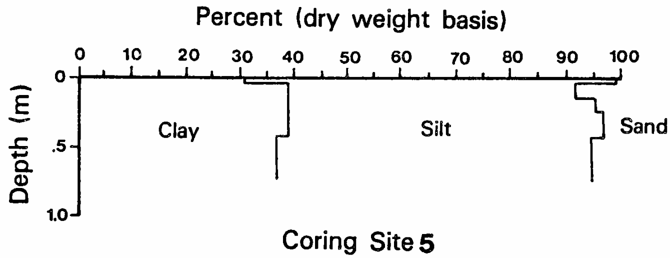


Figure 2-30 (cont.). Inorganic composition of Cedar Lake sediments from Cores 1, 2, and 5.

The textural classification for Core 1 shows that approximately one-half of the core was silty clays and the other half was silty-clay-loams. The silty-clay-loam textures were found either in the upper or lower sections of the Core. The sections of Cores 2 and 5 that were analyzed were more homogeneous with respect to particle size. All sections analyzed in Core 2 were categorized as silty clays and all sections in Core 5 were silty-clay-loams.

Metals. The presence of heavy metal contaminants in lake sediments is an important concern in the analysis of lake quality and restoration. Depending on conditions, sediments may be a source of trace metals to the water column, or they may be a sink for allochthonous or adsorbed inputs from the watershed.

Data obtained on the concentrations of metals in sediment can be useful in evaluating the metals in surface sediments which may be available to the water column, and for making proper evaluations for various operations involved in dredging. To the latter point, knowledge of such metal concentrations would be valuble in assessing the proper procedures for, and the applicability of, disposing dredge spoils.

An a-priori decision was made to analyze for five metals in Cedar Lake: lead, cadmium, zinc, copper, and iron. Because of their relatively toxic nature and the close proximity of Cedar Lake to the highly industrialized Calumet Region, lead and cadmium were of concern. In addition, the past inputs to the lake of sewage effluents prompted a survey for these two metals and for zinc. Copper sulfate was a chemical added to Cedar Lake for aquatic nuisance control, particularly algal blooms. Finally, iron was chosen for analysis because of the significant role it plays in the precipitation and release of phosphates in sediments.

The five metals that were examined are generally not bound to the internal structure of the sediment particles. Thus, the values presented here represent adsorbed or precipitated amounts which would be solublized in a slightly vigorous digestion.

Methods

Freeze-dried samples from sediment cores were solublized using a slightly vigorous digestion in hot nitric acid. Following digestion, the samples were filtered to remove silicates and large refractory agents, and then aspirated directly into an atomic absorption spectrophotometer.

Concentrations of each element were then determined employing a linear regression program of the standard curve according to Beer's Law for all absorbances less then 0.700. Dilutions and rotation of the burner assembly were used for determinations of more concentrated samples. A detailed description of analytical procedures used is presented in Appendix A.

Copper

Figure 2-31 presents total copper concentrations of sediments by depth, for Coring Sites 1, 2, and 5. Highest concentrations of copper were approximately 60 mg/kg (dry weight) and occurred in the upper portion of the cores. As depth increased, concentrations rapidly declined to around 35 mg/kg. The stable concentrations in the deeper sections of the cores (below 70 cm) represent historical levels. Historical levels for copper in lacustrine deposits have been reported by Forstner (1977) to be approximately 43 mg/kg which is similar to values measured at Cedar Lake.

The values measured in surface sediments from Cedar Lake fall within the wide range reported in the literature. Maximum copper concentrations for some Wisconsin lakes have been reported in excess of 200 mg/kg (Shukla et al. 1972; Syers et al. 1973), while values of 50 mg/kg have been reported for eutrophic Lake Washington (Barnes and Schell 1973). A mean value of 47 mg/kg was reported for Houghton Lake (Pecor et al. 1973).

Forstner (1977) suggests that as much as 80% of the copper present in lake sediments is anthoropogenic, due to inputs from diffuse sources and algicides. In the cores analyzed for Cedar Lake, the concentrations of copper in the upper 35 cm were approximately 40% higher than historic levels. While slight fluctuations throughout the cores are most likely due to changes in clay fraction, percent organic matter, erosional factors in the watershed and sedimentation rates, the large increase in total copper in the upper sediments probably results from human activities.

Increased copper levels in surface sediments of Cedar Lake may have been influenced by past application of copper sulfate for algae control. However, comparisons of Cedar Lake copper levels with other lakes treated with copper sulfate show that levels reporteed here may not be unusually high. Copper levels in lakes of the Yahara basin in Wisconsin which were treated with copper sulfate range from 223 mg/kg to 605 mg/kg. One sample from Lake Monona, Wisconsin, had concentrations of 1093 mg/kg (Hutchinson 1975). There is no information available on background levels or the type of digestions used in the copper analyses for these other lakes.

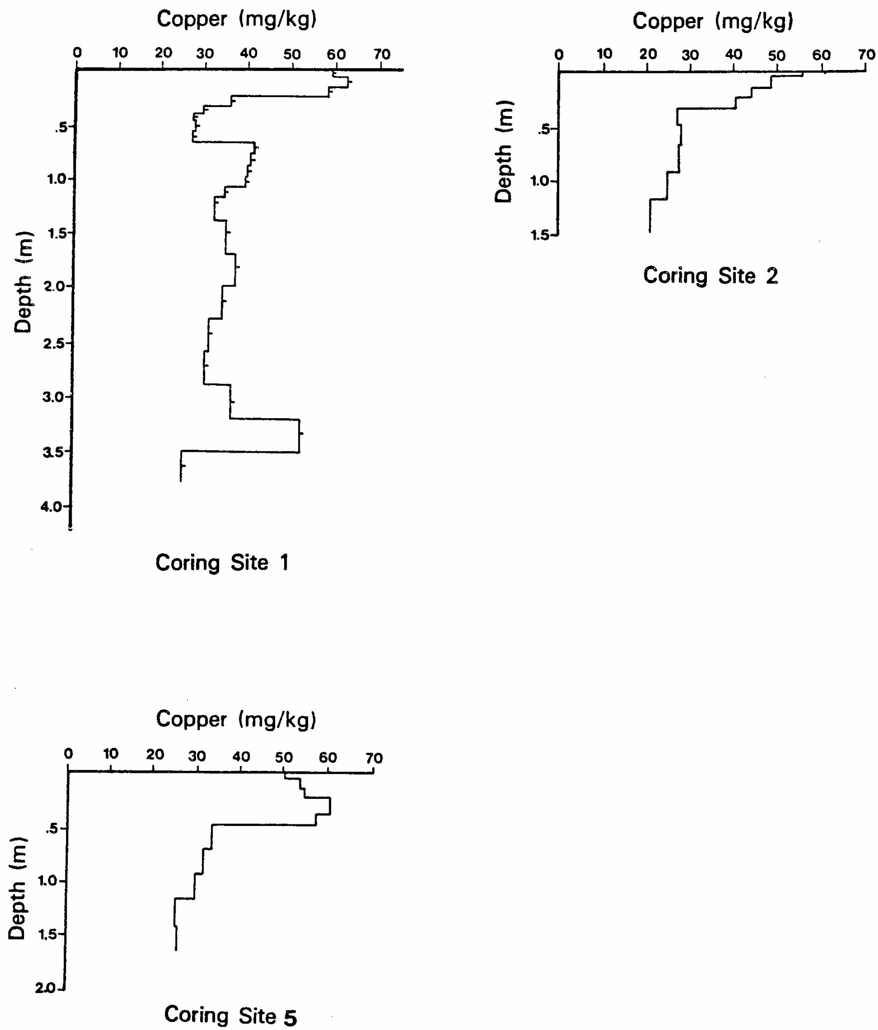


Figure 2-31. Copper concentrations in sediment cores from Cedar Lake in 1979.

Lead

Anthropogenic lead inputs to Cedar Lake sediments appear to be very important in influencing the shape of the plots shown in Figure 2-32. Large differences between upper layer sediments and deeper sections of the cores are obvious. Concentrations of approximately 105 mg/kg in the upper 25 centimeters represent a five-fold increase over concentrations in depths below 100 centimeters.

In Cores 1 and 2, lead concentrations declined rapidly below 25 cm then stablized at historical levels of between 25 and 30 mg/kg at lower depths. Lead concentrations in core 5 declined from peak levels to historic levels below 70 cm. A background concentration of lead in lacustrine deposits has been reported by Forstner (1977) to be approximately 28 mg/kg, which is similar to historic levels measured in Cedar Lake.

Forstner (1977) suggests that nearly 90% of the lead present in sediments from the Lower Rhine River (Germany) was due to cultural inputs. In the upper 20 cm of Cedar Lake sediments, approximately 80% of the lead content may be of cultural origin. Likely sources of lead are wastewater discharge and fossil fuel combustion, especially gasoline.

There is wide variability in literature values reported for lead concentrations in lake sediments and this variation is somewhat dependent on the types of major sources of inputs. Lead concentrations reported for Lake Washington were around 400 mg/kg, and were attributed to atmospheric fallout from smelters (Barnes and Schell 1973; Crecelius and Piper 1973). Other values reported by Shukla et al. (1972), and Syers et al. (1973) for Wisconsin Lakes were approximately 124 mg/kg and were attributed to algicides and herbicides. Rolfe and Jennett (1975) reported concentrations in urban stream sediments of 350 mg/kg due to inputs of leaded gasoline combustion products.

Zinc

Figure 2.33 presents plots of zinc concentrations with depth for Cores 1, 2 and 5. In Cores 1 and 2, the highest zinc concentrations were between 200 and 231 mg/kg and occurred in the upper 25 cm of sediment. These levels declined to between 50-80 mg/kg in sediments below 40 cm. In Core 5 the highest zinc concentration of 240 mg/kg occurred in the upper 50 cm and declined to around 80 mg/kg below 70 cm.

Concentrations in the upper layers of Cedar Lake cores are 3-4 times greater than the historical levels of approximately 65 mg/kg in the deeper sections. This increase is probably of anthropogenic origin. Cultural influences on zinc concentrations in lacustrine sediments are relatively high in most lakes. Values reported for Lake Washington and various Wisconsin lakes are from 4 to 6 times higher in surface sediments than background levels. Some reported concentrations of zinc given in the literature are 92 mg/kg for

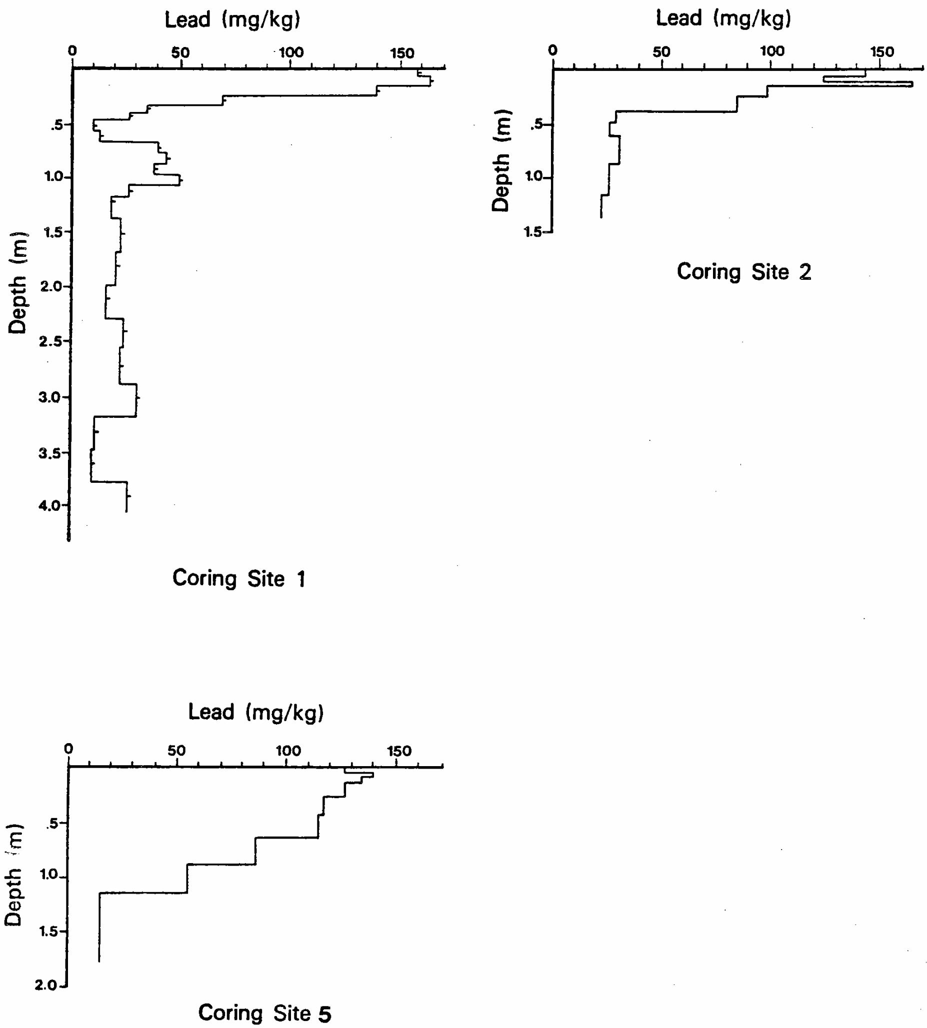
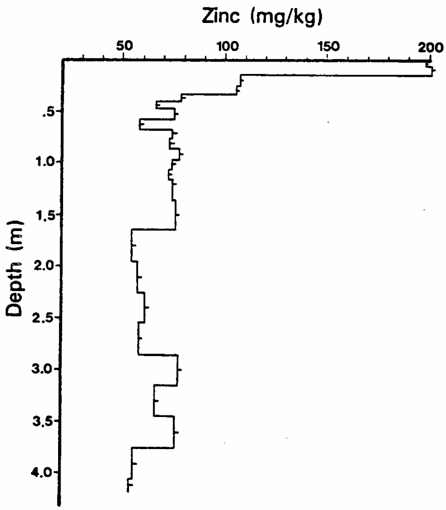
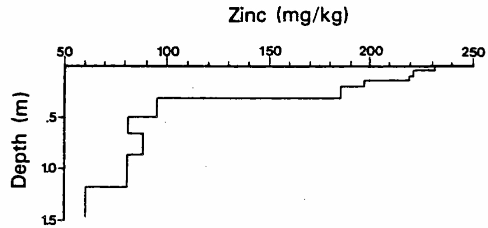


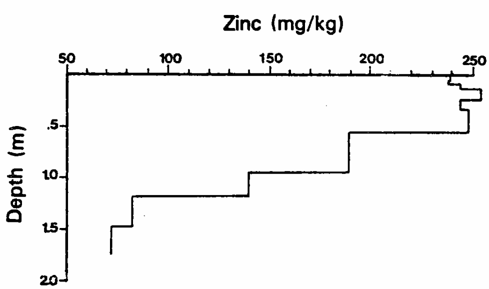
Figure 2-32. Lead concentrations in sediment cores from Cedar Lake in 1979.



Coring Site 1



Coring Site 2



Coring Site 5

Figure 2-33. Zinc concentrations in sediment cores from Cedar Lake in 1979.

Wisconsin Lakes (Forstner 1977), and 230 mg/kg for Lake Washington (Barnes and Schell 1973; Crecelius and Piper 1973), and 570 mg/kg for Wapato Lake (Entranco Engineers 1978).

Cadmium

Figure 2-34 shows concentrations of cadmium for various depths of Cores 1, 2, and 5 from Cedar Lake. The general trend evident for previous metals, showing peak concentrations in the upper layers of sediment, was also found for cadmium. Maximum levels reached 3.55 mg/kg in Core 5 and 1.75 mg/kg and 3.01 mg/kg respectively for Cores 1 and 2. Because of the low historical levels for cadmium, the analysis approached detection limits in the deeper sections. Thus, the wide fluctuations occurring in the deepest sections of the core are most likely a function of the low signal to noise ratio for those determinations on the atomic absorption spectrophotometer.

Two literature sources (Shimp et al. 1971; Barnes and Schell 1973), report cadmium background levels as undetectable, while others (Forstner 1977) give concentrations as high as 2.5 mg/kg. While the limited detection range of the spectrophotometer used made it difficult to accurately measure cadmium levels in Cedar Lake sediments, it is apparent that the surficial sediment concentrations show the impact of cultural inputs. Whether these inputs are a function of direct cadimum discharges is not known. However, Forstner (1977) reports that only two per cent of the cadmium content of sediments from the Lower Rhine is of natural origin; the remaining 98% being derived from urban and agricultural runoff and atmosphere pollution.

Iron

Laboratory results indicate that cultural influences on Cedar Lake's sediments are relatively low for iron (Figure 2.35). Peak concentrations of iron did not occur in the upper sediment sections, in contrast to other heavy metals analyzed. Forstner (1977) has reported similar findings for sediments from the Lower Rhine River, where virtually 100% of the iron content is of natural origin.

Inspection of Figure 2-35 shows that while there is some slight variation between cores, iron content in Cedar Lake sediments is approximately 3000 mg/kg. While some authors (Forstner 1977; Agemain and Chou 1976) report iron levels as high as 42,000 mg/kg, it must be noted that high levels may be a function of geologic variation and the ability of the particular digestion used in the analysis to attack the crystalline structure of the sediment. Theis (1979) has reported iron values for a eutrophic, northern Indiana, lake, using a nitric acid digestion, of 3700 mg/kg which is similar to that reported here.

Summary

By core sampling through the deepest sediments of the lake, the influence of anthropogenic metal inputs to Cedar Lake sediment were made apparent. Highest concentrations exist in the upper layers of

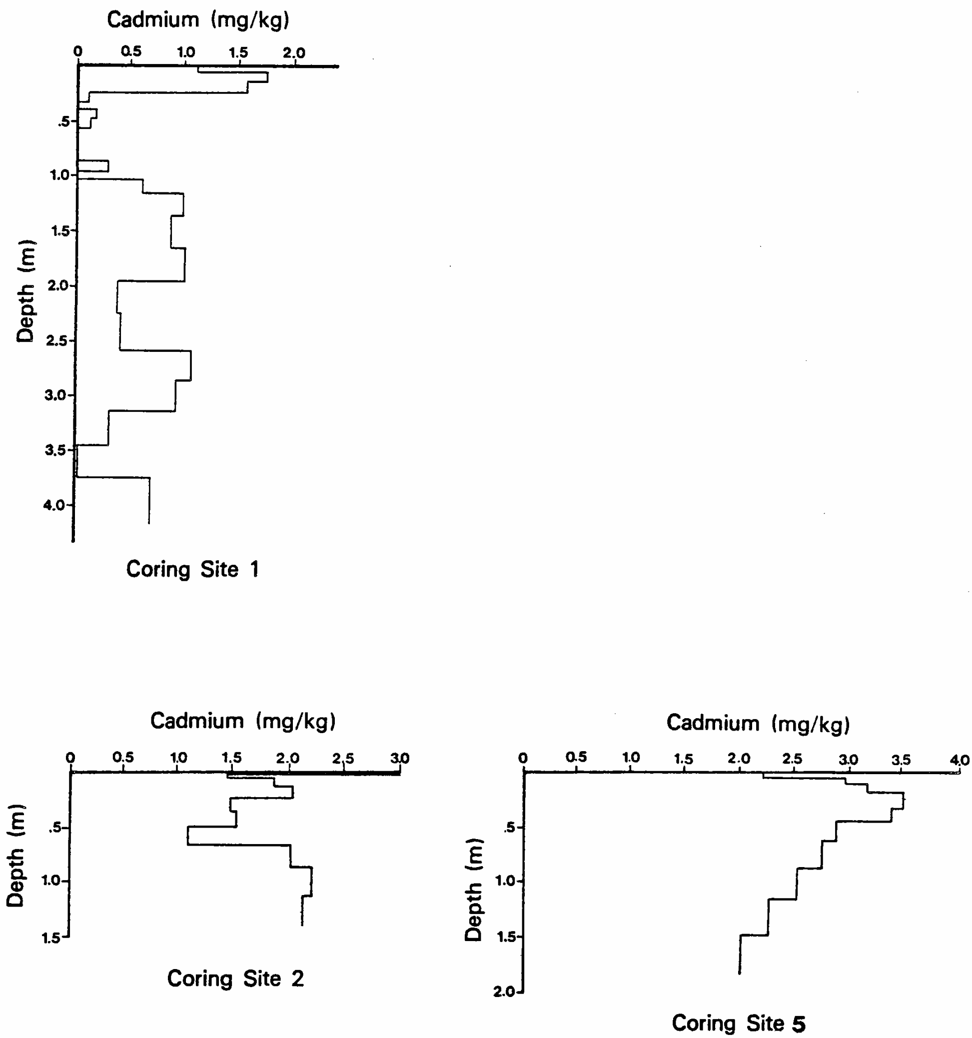


Figure 2-34. Cadmium concentrations in sediment cores from Cedar Lake in 1979.

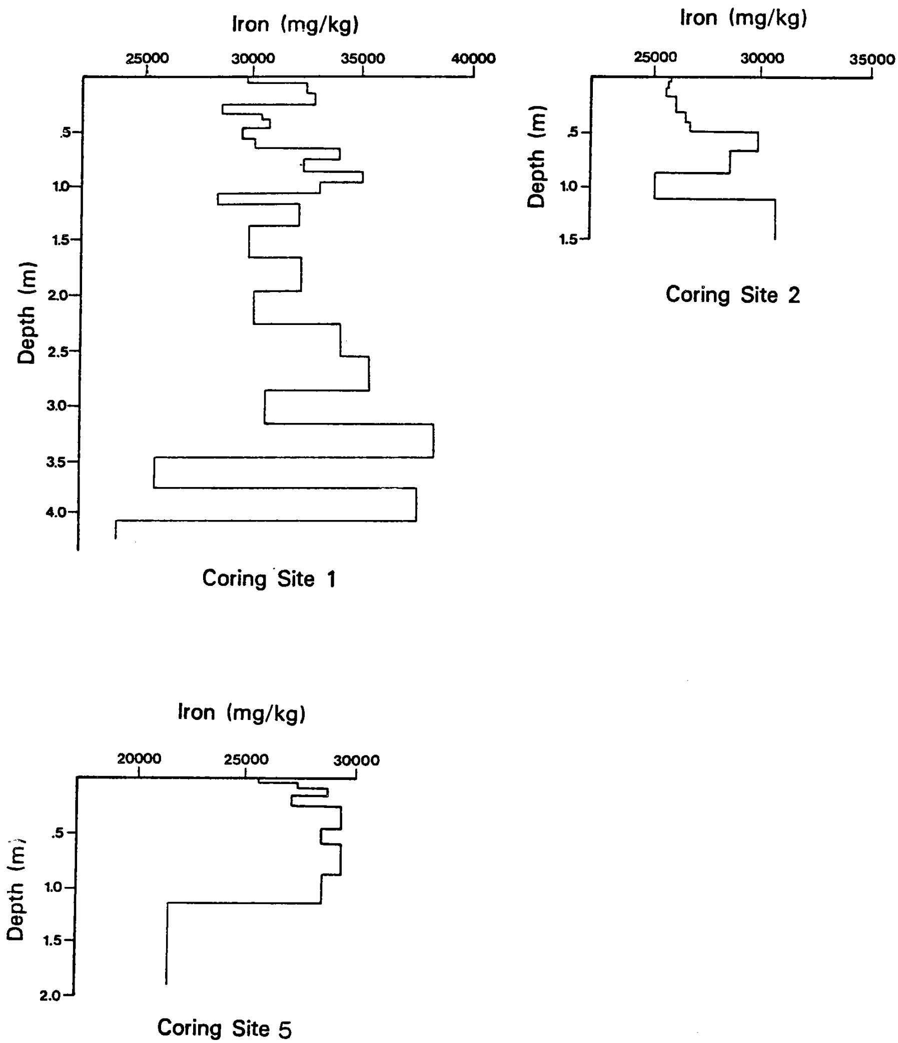


Figure 2-35. Iron concentrations in sediment cores from Cedar Lake in 1979.

the core. Except in the case of iron, concentrations rapidly decline with increasing depth and eventually level off to nearly constant values (usually below 50 cm) representative of the natural historic levels.

Metal concentrations in sediment Core 5 remain elevated to greater depths than concentrations in Cores 1 and 2. This may be due to the higher sedimentation rates estimated for the south basin where Core 5 was extracted.

The U.S. Environmental Protection Agency (1977) has established preliminary guidelines for Region V for the classsification and evaluation of the metal content of sediments. Sediments are classified as heavily polluted, moderately polluted, or unpolluted by evaluating the measured concentration against the ranges given for each metal. These guidelines were developed in consideration of the need to make proper decisions regarding the disposal of dredged material in waterways. The guidelines are not intended to be used in decisions regarding the upland disposal of dredged materials. At present, EPA considers this classification as an interim guideline until more scientifically sound guidelines are developed.

The guidelines classify sediments based on several factors. One of these factors is metals content. The maximum metal concentrations measured in the sediment cores from Cedar Lake were compared to the values reported in the EPA guidelines.

Table 2-13 presents the measured values from the cores with the EPA concentration ranges and classification. As is evident from the table, the Cedar Lake sediments are classified by these guidelines as either moderately or heavily polluted for all metals analyzed except cadmium. Lower limits for cadmium classification have not yet been established.

Table 2-13. Classification of Cedar Lake sediments according to interim guidelines established by Region V, U.S. Environmental Protection Agency.

	Lead	Zinc	Copper	Cadmium	Iron
Mean Concentrations Cedar Lake (mg/kg)	111	118	47	1.9	28,471
Maximum Concentrations Cedar Lake (mg/kg)	166	255	62	3.6	32,500
EPA Range Values (mg/kg)	60	200	50	6	25,000
Classification For Mean Concentration Values	Heavily Polluted	moderately Polluted	Moderately Polluted		Heavily Polluted

Concentrations of lead, zinc, copper, and iron in Cedar Lake sediments were within ranges reported by several authors, as stated previously. Natural background levels of these metals, especially iron, can be high enough to fall within the moderately or heavily polluted ranges for the EPA interim guidelines. It is not known how the guidelines, once finalized, will account for additional cultural loadings of metals to sediments which already have high natural loadings.

2.5.3 Sediment Elutriate Test

The U.S. Army Corps of Engineers (1976) has developed a standard elutriate test to predict pollutant releases resulting from dredging. The test is designed to simulate conditions within the pipeline of a hydraulic dredge and the results are used to predict the level of pollutants either released from or adsorbed to the sediments during dredging. Results of elutriate tests have also been used to evaluate the release of pollutants from in situ lake sediments during turbulent mixing by wind and boats (R. Peddicord, U.S. Army Corps of Engineers, personal communication).

Method. Sediment samples were collected with a Ponar sampler at four sites within Cedar Lake (Figure 2-3). Water samples from each site were also collected and all samples were kept at 4°C until analyzed. Within one week of collection, sediments and lake water were combined in a 1:4 ratio and mixed for one-half hour. The overlying water was then filtered and analyzed for total phosphorus, TKN, and metals according to methods presented in Appendix A for water. The results were then compared to total phosphorus, TKN, and metals levels in the water before mixing. A detailed description of the elutriate test analytical procedure is presented in Appendix A.

Results. The results from the elutriate test are presented in Table 2.14. At Sites 1, 2, and 3, phosphorus in the lake water was adsorbed to the sediments during mixing. Only at Site 4 did the sediments release phosphorus during mixing. Concentrations of the metals analyzed were not detectable in the elutriate following mixing.

Only the elutriate from Site 3 was analyzed for TKN. Significant quantities of TKN were released from the sediments at this site during mixing. This difference averaged 7980 ug/l for the two replicates and probably consists mostly of ammonia since all water samples were filtered thru 0.45u filters. This step traps most of the organic nitrogen, leaving only soluble nitrogen in the elutriate. Because of the particular TKN method used, ammonia was the only soluble form of nitrogen measured.

Discussion. The adsorption of phosphorus from the water column to sediments during an elutriate test is not uncommon, especially when the tremendous adsorptive capacity of the finer sediments is considered (Peddicord, personal communication). This result suggests that the sediments in Cedar Lake were somewhat low in available phosphorus by late July (1979) when samples for the elutriate test were acquired. To test for this, summer grab samples of sediments were taken from Coring Sites 1, 2, and 5 and analyzed

Table 2-14. Elutriate test results. (-) indicates release from sediments; (+) indicates adsorption to sediments; (ND) indicates None Detectable.

Sample Date	Site	Total P(ug/l) Before	After	Difference	TKN(ug/l)* Before	After	Difference	Fe,Cu,Pb,Zn,CD
7-20	1	149.7	74.9	+ 74.8				ND
	1	149.7	75.1	+ 74.6				ND
7-20	2	149.7	74.9	+ 74.8				ND
	2	148.7	74.9	+ 74.8				ND
8-03	3	230.0	119.0	+111.0	3490	11320	-7830	ND
		230.0	118.0	+112.0	3490	11620	-8130	ND
8-31	4	92.0	121.0	- 29.0				ND
	4	92.0	109.0	- 17.0				ND

*Due to the method used, this is predominantly the ammonia fraction of TKN.

for phosphorus concentration per dry weight, using the same analytical procedures used for sediment core analyses. The results of this analysis are presented in Table 2-15.

Table 2-15. Comparison of phosphorus concentrations per dry weight of sediment for winter and summer sediments (1979) from Cedar Lake.

Sample Site	Average phosphorus concentration (ug/g) Winter cores (0-30cm)	Summer grab samples
Coring site 1	845	846
Coring site 2	820	657
Coring site 5	873	725

The lower phosphorus concentrations in the summer samples from Sites 2 and 5 suggest that Cedar Lake sediments function as a source of phosphorus to the overlying water column during the summer months and a phosphorus sink during the winter months. Winter vs. summer phosphorus concentrations from the Site 1 sample were virtually unchanged.

The release of large quantities of nitrogen, as ammonia, also occurred during the elutriate test. Ammonia tends to accumulate in sediments containing appreciable amounts of organic matter. Release of ammonia, however, is greatest under anoxic conditions (Wetzel 1975). Results of water analyses conducted at Cedar Lake (see Section 2.2) show that conditions of very low dissolved oxygen concentration existed at the bottom of Cedar Lake during periods of calm weather. The release of ammonia during the elutriate test may have been facilitated by these conditons.

Metals were not detectable in the final elutriate test from any of the samples due in part, to the high affinity that fine sediments have for certain metals. Metals adsorbed to sediment particles and those which form complexes were probably trapped in the 0.45 micron filter during filtration and did not appear in the elutriate that was analyzed. Since the dissolved fraction of metals was so low, little was available to be detected. Grimwood and McGhee (1979) found this to be a limitation of the standard elutriate test, particularly for lead, mercury, and copper.

Summary. Tentative conclusions suggest that physical mixing of Cedar Lake sediments under oxygenated conditions will not cause the release of large quantities of total phosphorus or the five metals analyzed. The analyses also showed that nitrogen is released with physical mixing. There is some evidence to suggest that sediment release of phosphorus may be a function of the time of year in which the sediments are agitated.

2.5.4 Distribution of Sediment Textures

On September 15, 1979, grab samples of Cedar Lake surfacial sediments were taken with a Ponar sampler to determine the boundaries of textural classes. Sample were taken along eight transects around the lake at successively deeper depths (Figure 2-36). The sediment grabs were analyzed by sight and touch for coarse (sand and gravel) and fine (silt and clay) textures and organic matter. Figure 2-36 illustrates a rough approximation of the transition zone between sandy (and often gravelly) sediments found in shallow areas and silt-clay sediments found in deeper parts of the lake. This yields a crude estimate of 1.4 million m^2 of lake surface sediments composed of sand and gravel and 1.8 million m^2 composed of silts and clays. Occasionally highly organic sediments were found but no explainable pattern was evident.

2.5.5 Phosphorus Release From Sediments

Historical nutrient loadings to Cedar Lake have built up an enriched layer of phosphorus in the upper 30 cm of lake sediments (see section 2.5.2). This layer of sediments is suspected of contributing 70-90% of the water column phosphorus in the lake through internal recycling (see Chapter 4, Nutrient Budget). Sediment column tests were therefore conducted in the laboratory to determine phosphorus release rates from the current sediment level, and from the 50 cm level to simulate conditions following a limited dredging program.

Methods. Intact sediment cores from Cedar Lake were collected in February, 1982 and again in August, 1982 using a piston corer with 7 cm diameter acrylic plastic coring tubes. Care was taken to not disturb the sediment-water interface during collection. Eight cores were taken. The upper 50 cm of sediment in four of the cores were extruded on site to approximate the new sediment-water interface that would result from a shallow dredging program, if one were conducted. The overlying water from the remaining four cores was syphoned off. The cores were then packed upright in ice and returned to the laboratory.

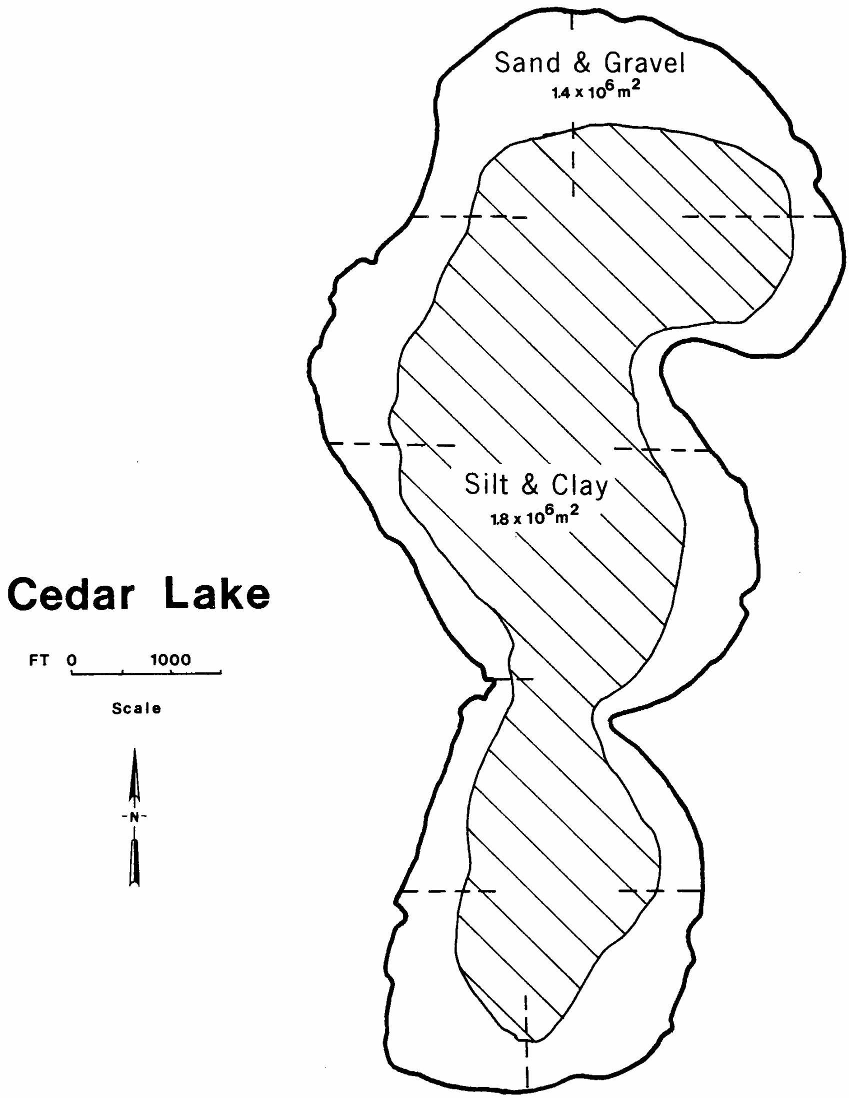


Figure 2-36. Textural classification of surficial sediments in Cedar Lake.

In the laboratory, the overlying water was replaced with filtered (Whatman GFC) water, having known soluble reactive phosphorus (SRP) and total phosphorus (TP) concentrations, that had been collected at the same location as the cores. Each of the eight sediment columns contained 50 cm of sediments overlain by 50 cm of water. Four remaining coring tubes were filled to a depth of 0.5 meter with lake water to serve as controls. The columns were positioned upright in a wooden frame which was placed in a controlled environmental chamber at 24°C, the ambient water temperature in Cedar Lake at the time of collection (Figure 2-37).

Experimental conditions for all columns are illustrated in Table 2-16. Oxic conditions were maintained by bubbling air through the water column at a point near enough to the sediments to allow complete mixing of the water but without disturbing the sediments. Nitrogen gas (99.9% pure) was bubbled through columns to maintain anoxic conditions.

Table 2-16. Sediment Column Test Design.

Gas Treatment	Surface sediment exposed (S)	50 cm sediment removed (D)	Control (C)
O_2	2 columns	2 columns	2 columns
N_2	2 columns	2 columns	2 columns

Each day, pH and dissolved oxygen were measured <u>in situ</u> using probes and a 100 ml water sample was withdrawn from each column to determine SRP and TP concentrations. SRP was determined colorimetrically according to Murphy and Riley (1962) while TP was determined through nitric acid-sulfuric acid digestion (APHA 1980) followed by colorimetric analysis (Murphy and Riley 1962). Filtered lake water was used to replace the water removed for analysis. Mass balances were calculated to determine the effect of the added lake water for each day. The winter experiment ran for three days until the nitrogen gas supply was exhausted. The summer experiment ran five days.

On the sixth day of the summer experiment, the sediments were vigorously mixed and resuspended to simulate in-lake physical mixing due to motor boats and high winds. Three days were allowed for settling before the water was analyzed for SRP and TP.

<u>Results.</u> All data from these experiments are presented in Tables 2-17 to 2-20. The change in SRP and TP water column concentrations is illustrated in Figure 2-38. The effects of oxygen concentrations are apparent. Anoxic columns released substantially larger quantities of SRP than the oxygenated columns (Figure 2-39). Following mixing of the sediments, the anoxic columns released more SRP while SRP was adsorbed in the oxygenated columns.

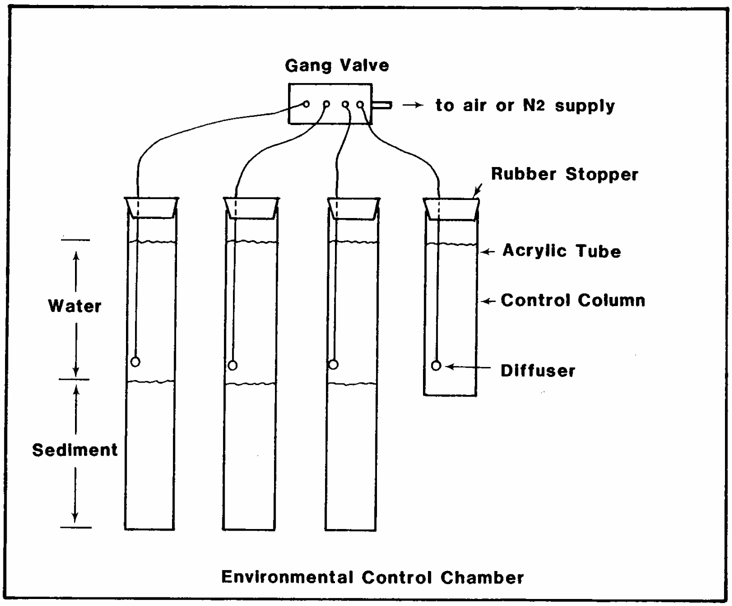


Figure 2-37. Sediment column test apparatus.

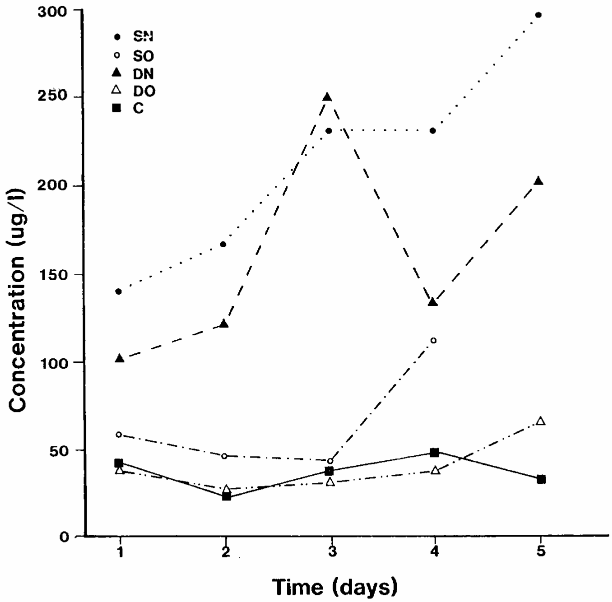


Figure 2-38. Water column phosphorus concentration changes due to sediment release from summer cores (1982).

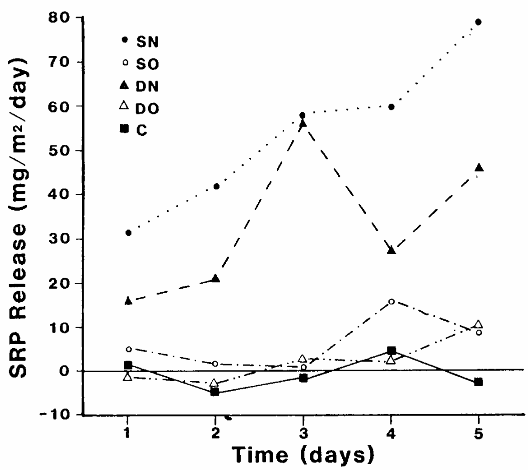


Figure 2-39. Cumulative phosphorus release from sediments from summer cores (1982).

Table 2-17a. Sediment phosphorus release data[1].
2-4-82

Core	Days Since Start of Experiment	SRP Initial (ug/l)	SRP Final (ug/l)	SRP Release Rate ($mg/m^2/day$)[2]	pH	Dissolved Oxygen (mg/l)
C_1O	1	29.8	26.9	-0.75	8.3	10.0
C_2O	1	30.2	26.9	-0.86	8.4	9.9
C_1N	1	28.6	27.4	-0.30	9.1	1.2
C_2N	1	30.7	28.7	-0.54	9.2	2.5
S_1O	1	29.0	27.9	-0.28	10.0	8.2
S_2O	1	29.8	28.2	-0.41	9.9	8.2
S_1N	1	29.0	28.7	-0.09	9.0	1.3
S_2N	1	31.0	22.7	-2.15	9.1	2.4
D_1O	1	28.3	26.4	-0.48	8.1	10.2
D_2O	1	29.0	27.4	-0.41	8.1	9.4
D_1N	1	28.3	26.4	-0.48	9.1	1.5
D_2N	1	29.8	25.5	-1.12	8.7	2.3

[1]Temperature held at 3°C

[2]One-day rate, since previous day, not cumulative. (+) indicates release from sediments, (-) indicates sediment uptake.

Table 2-17b. Sediment phosphorus release data[1].
2-5-82

Core	Days Since Start of Experiment	SRP Initial (ug/l)	SRP Final (ug/l)	SRP Release Rate ($mg/m^2/day$)[2]	pH	Dissolved Oxygen (mg/l)
C_1O	2	27.2	29.1	+0.48	7.6	9.4
C_2O	2	27.2	30.0	+0.71	7.3	11.0
C_1N	2	27.7	28.9	+0.32	8.9	1.1
C_2N	2	22.0	31.2	+2.40	9.0	0.4
S_1O	2	28.1	28.1	+0.00	7.4	12.2
S_2O	2	28.3	27.4	-0.24	7.4	12.6
S_1N	2	22.0	31.3	+2.44	9.1	0.4
S_2N	2	23.5	30.0	+1.67	8.9	0.5
D_1O	2	26.8	25.5	-0.35	7.5	9.6
D_2O	2	27.7	28.9	+0.31	7.2	11.2
D_1N	2	26.8	26.1	-0.18	8.4	1.2
D_2N	2	25.9	33.5	+1.97	8.5	1.4

[1]Temperature held at 3°C

[2]One-day rate, since previous day, not cumulative. (+) indicates release from sediments, (-) indicates sediment uptake.

Table 2-17c. Sediment phosphorus release data[1]. 2-6-82

Core	Days Since Start of Experiment	SRP Initial (ug/l)	SRP Final (ug/l)	SRP Release Rate ($mg/m^2/day$)[2]	pH	Dissolved Oxygen (mg/l)
C_1O	3	29.1	27.7	-0.37	7.6	13.0
C_2O	3	29.9	27.2	-0.69	7.5	12.4
C_1N	3	29.0	30.7	+0.44	8.5	2.8
C_2N	3	31.0	30.0	-0.26	8.8	0.9
S_1O	3	28.3	26.6	-0.45	7.4	12.5
S_2O	3	27.6	25.9	-0.46	7.6	12.5
S_1N	3	31.1	28.1	-7.72	8.6	2.4
S_2N	3	29.9	29.5	-0.10	8.5	2.2
D_1O	3	25.9	26.8	+0.23	7.5	12.6
D_2O	3	28.9	27.5	-0.38	7.4	12.4
D_1N	3	26.5	28.8	+0.62	8.6	1.7
D_2N	3	33.0	28.4	-1.21	8.4	3.2

[1]Temperature held at 3°C.

[2]One-day rate, since previous day, not cumulative. (+) indicates release from sediments, (-) indicates sediment uptake.

Table 2-18a. Sediment phosphorus release data. 8-19-82

Core	Days Since Start of Experiment	SRP Initial (ug/l)[1]	SRP Final (ug/l)	SRP Release Rate ($mg/m^2/day$)[2]	Total P Initial (ug/l)	Total P Final (ug/l)	Total P Release Rate ($mg/m^2/day$)[2]	pH	Dissolved Oxygen (mg/l)
C_1O	1	41	38	- 0.78	--	220	--	7.6	7.0
C_2O	1	41	39	- 0.52	--	220	--	7.6	7.2
C_1N	1	41	52	+ 2.9	--	208	--	8.3	0.4
C_2N	1	41	34	- 1.8	--	244	--	8.8	0.3
S_1O	1	41	57	+ 4.2	--	272	--	7.6	6.9
S_2O	1	41	60	+ 4.9	--	272	--	7.7	6.9
S_1N	1	41	147	+27.5	--	408	--	8.8	0.3
S_2N	1	41	137	+35.6	--	328	--	8.6	0.3
D_1O	1	41	40	- 0.30	--	244	--	7.7	7.0
D_2O	1	41	40	- 0.30	--	296	--	7.7	7.2
D_1N	1	41	87	+12.0	--	284	--	8.6	0.2
D_2N	1	41	118	+20.0	--	544[3]	--	9.0	0.2

SRP concentration in replacement water = 40 ug/l.

[1]Represents concentration of SRP in original make-up water.

[2]One day rate, since previous day's measurement; not cumulative. (-) signifies release from sediments, (+) signifies sediment uptake SRP concentration in replacement water = 40 ug/l.

[3]Contaminated.

Table 2-18b. Sediment phosphorus release data.
8-20-82

Core	Days Since Start of Experiment	SRP Initial (ug/l)	SRP Final (ug/l)	SRP Release Rate (mg/m²/day)[2]	Total P Initial (ug/l)	Total P Final (ug/l)	Total P Release Rate (mg/m²/day)	pH	Dissolved Oxygen (mg/l)
C_1O	2	38	14	- 6.2	220	136	-21.8	7.5	7.0
C_2O	2	39	24	- 3.9	220	156	-16.6	7.6	6.6
C_1N	2	51	39	- 3.1	208	168	-10.4	8.6	0.3
C_2N	2	34	9	- 6.5	244	232	- 3.1	9.0	0.2
S_1O	2	56	45	- 2.9	272	184	-22.9	7.5	6.9
S_2O	2	59	48	- 2.9	272	160	-29.1	7.5	7.0
S_1N	2	142	183	+10.7	408	380	-72.8	9.1	0.1
S_2N	2	132	172	+10.4	328	340	+ 3.1	8.9	0.1
D_1O	2	40	28	- 3.1	244	168	-19.7	7.6	6.9
D_2O	2	40	24	- 4.2	296	320	+ 6.2	7.6	6.5
D_1N	2	85	101	+ 3.6	284	252	- 8.3	8.9	0.2
D_2N	2	114	140	+ 6.8	544	528	- 4.2	9.0	0.2

SRP concentration in replacement water = 42/ug/l

[1]One-day rate, since previous day's measurement; not cumulative. (+) signifies release from sediments
(-) signifies sediment uptake.

Table 2-18c. Sediment phosphorus release data.
8-21-82

Core	Days Since Start of Experiment	SRP Initial (ug/l)	SRP Final (ug/l)	SRP Release Rate (mg/m²/day)[1]	Total P Initial (ug/l)	Total P Final (ug/l)	Total P Release Rate (mg/m²/day)	pH	Dissloved Oxygen (mg/l)
C_1O	3	15.4	5	- 2.7	136	172	+ 19.7	7.6	5.0
C_2O	3	25	43	+ 5.2	156	172	+ 4.2	7.9	5.2
C_1N	3	39	43	- 1.0	168	444	+ 71.1	8.8	0.2
C_2N	3	11	58	+12.7	232	232	0.0	9.2	0.2
S_1O	3	45	56	+ 3.4	164	324	+ 36.4	7.9	4.9
S_2O	3	48	28	- 5.2	160	476	+ 82.1	7.9	4.9
S_1N	3	176	248	+18.7	380	1140	+197.5	9.2	0.3
S_2N	3	166	217	+13.3	340	928	+152.8	9.1	0.1
D_1O	3	29	13	+ 4.2	168	232	+ 16.6	7.8	4.6
D_2O	3	25	51	+ 6.6	320	2292[2]	--	7.9	4.7
D_1N	3	96	225	+33.0	252	476	+ 58.2	9.0	0.1
D_2N	3	135	285	+39.0	528	776	+ 64.4	9.2	0.3

SRP concentration in replacement water = 66 ug/l.

[1]One-day rate, since previous day's measurement; not cumulative. (+) signifies release from sediments,
(-) signifies sediment uptake.

[2]Contaminated.

Table 2-18d. Sediment phosphorus release data. 8-22-82

Core	Days Since Start of Experiment	SRP Initial (ug/l)	SRP Final (ug/l)	SRP Release Rate (mg/m²/day)[1]	Total P Initial (ug/l)	Total P Final (ug/l)	Total P Release Rate (mg/m²/day)	pH	Dissolved Oxygen (mg/l)
C_1O	4	8	50	+10.9	172	392	+ 57.2	6.8	7.4
C_2O	4	44	50	+ 1.6	172	332	- 41.6	7.3	7.6
C_1N	4	44	79	+ 9.1	444	356	+ 22.9	8.0	0.3
C_2N	4	58	50	+ 0.5	232	240	+ 2.1	8.5	0.3
S_1O	4	58	126	+12.2	324	584	+ 67.6	7.2	7.4
S_2O	4	30	98	+17.7	476	584	+ 28.1	7.2	7.5
S_1N	4	239	231	- 2.1	1140	732	-106.0	8.7	0.3
S_2N	4	209	231	+ 5.7	928	660	- 69.6	8.4	0.2
D_1O	4	16	41	+ 6.5	232	432	+ 52.0	7.0	7.6
D_2O	4	52	36	- 4.2	2292[2]	356	-503.1	7.2	7.6
D_1N	4	217	117	-26.0	476	468	- 2.1	8.4	0.2
D_2N	4	274	146	-33.3	776	584	- 49.9	8.4	0.2

SRP concentration in replacement water = 41 ug/l.

[1]One-day rate, since previous day's measurement; not cumulative (+) signifies release from sediments, (-) signifies sediment uptake.

[2]Contaminated.

Table 2-18e. Sediment phosphorus release data. 8-23-82

Core	Days Since Start of Experiment	SRP Initial (ug/l)	SRP Final (ug/l)	SRP Release Rate (mg/m²/day)[1]	Total P Initial (ug/l)	Total P Final (ug/l)	Total P Release Rate (mg/m²/day)	pH	Dissolved Oxygen (mg/l)
C_1O	5	50	22	- 7.3	392	132	-67.6	6.5	7.7
C_2O	5	50	33	- 4.4	332	164	-43.7	7.2	7.8
C_1N	5	77	46	- 8.1	356	164	-49.9	7.8	0.7
C_2N	5	50	22	- 7.3	240	191	-12.7	7.9	0.7
S_1O	5	122	360[2]	+61.8[2]	584	514	-18.1	7.1	7.9
S_2O	5	95	68	- 7.0	584	255	-85.5	7.2	7.7
S_1N	5	222	317	+24.7	732	557	-45.5	8.4	0.1
S_2N	5	222	275	+13.7	660	411	-89.6	7.9	0.1
D_1O	5	41	63	+ 5.7	432	196	-61.3	7.2	7.7
D_2O	5	36	68	+ 8.3	356	202	-40.0	7.2	7.7
D_1N	5	113	196	+20.5	468	352	-30.1	8.2	0.2
D_2N	5	141	209	+17.7	584	261	-83.9	7.9	0.2

[1]One-day rate, since previous day's measurement; not cumulative. (+) signifies release from sediments. (-) signifies sediment uptake.

[2]Contaminated.

In both the oxic and anoxic columns, the surface sediment columns (S) showed greater release of SRP than the 50 cm sediment level columns (D): a 188% increase in SRP concentration and 151% increase in SRP release rate in oxygenated columns and a 54% increase in SRP concentration and 129% increase in SRP release rate in anoxic columns.

There was also a marked difference in the concentration of TP between the anoxic and oxygenated cores at the end of the experiment. Replicate cores were averaged together. In comparing the original sediment-water interface cores to the simulated dredged cores under oxygenated conditions, there was 32.5% difference in the concentrations of TP at the end of the experiment between the two sets. The anoxic cores exibited a 29.4% difference between the original sediment-water interface cores and the simulated dredged cores. Release rates for TP were not calculated using a mass balanced approach. Therefore, actual TP release rates may be slightly different.

Discussion. Since sediment data exist for only two periods, certain assumptions must be made regarding application to the lake as a whole. Cedar Lake clearly has a summer and winter season. Previous data (Section 2.2.1) show low oxygen concentrations above the sediments during the summer and so it is assumed that anoxic SRP core data are applicable to this time of the year. The average net SRP released (from S_1N and S_2N) is 11.9 $mg/m^2/d$ (Table 2-19). Winter core data do not show any substantial difference between oxic and anoxic cores. If these winter data are pooled, there is a net uptake of phosphorus by the sediments equal to 0.65 $mg/m^2/d$.

If it is assumed that August and February represent the two extremes of yearly phosphorus release and uptake (see Holdren and Armstrong 1980), then the average of the mean release rates observed in the core experiments can serve as a good approximation of mean annual SRP release. The average of these is 5.63 $mg/m^2/d$ or 2.05 $g/m^2/yr$ of net released SRP into Cedar Lake. This value agrees rather well with estimtes of internal loadings of phosphorus to Cedar Lake of 1.65 to 2.19 $g/m^2/yr$ (see Chapter 4).

The average mean SRP release rates from the cores simulating dredging are 0.12 $mg/m^2/d$ (D_1O, D_2O, D_1N, and D_2N) for February and 7.85 $mg/m^2/d$ (D_1N and D_2N) for August. The average of these is 3.99 $mg/m^2/d$ or 1.46 $g/m^2/yr$. This represents a reduction of 29% in internal SRP loadings over the non-dredged sediments.

The greatly increased release rates for SRP and TP following mixing of the upper 10cm (Table 2-20) indicate how sensitive Cedar Lake sediments are to mixing, either by wind or motor boat activity (see also Section 4.7).

2.6 BIOLOGICAL ENVIRONMENT

2.6.1 Algae

Field Methods. Algae samples were collected at the same sites as water quality samples (Figure 2-1). When investigations began,

Table 2-19. Sediment SRP release data summeries.

Core	February 1982 Total Days Run	Initial (ug/l)	Final (ug/l)	Mean Release Rate (mg/m²/day)[1]	August 1982 Total Days Run	Initial (ug/l)	Final (ug/l)[2]	Mean Release Rate (mg/m²/day)[1]
C_1O	3	29.8	27.7	-0.18	4	38	17.6	- 1.3
C_2O	3	30.2	27.2	-0.26	4	39	31	- 0.52
C_1N	3	28.6	30.7	+0.18	4	52	48	- 0.26
C_2N	3	30.7	30.0	-0.06	4	34	24	- 0.65
S_1O	3	29.0	26.6	-0.21	3	57	134	+ 6.7
S_2O	3	29.8	25.9	-0.39	4	60	70	+ 0.65
S_1N	3	29.0	26.1	-0.08	4	147	347	+13.0
S_2N	3	31.0	29.5	-0.13	4	137	303	+10.8
D_1O	3	28.3	26.8	-0.13	4	40	59	+ 1.3
D_2O	3	29.0	27.5	-0.13	4	40	66	+ 1.7
D_1N	3	28.3	28.8	+0.04	4	87	213	+ 8.2
D_2N	3	29.8	28.4	-0.12	4	118	234	+ 7.5

[1]First day not included. (+) signifies release from sediments. (-) signifies sediment uptake.

[2]Corrected for additional phosphorus added by make-up water

Table 2-20. Sediment phosphorus release data following sediment mixing.[1]

Core	SRP Initial (ug/l)	SRP Final (ug/l)	SRP Release Rate (mg/m²/day)	Total P Initial (ug/l)	Total P Final (ug/l)	Total P Release Rate (mg/m²/day)	pH	Dissolved Oxygen (mg/l)
C_1O	22	18	- 1.0	--	--	--	7.2	7.2
C_2O	33	27	- 1.6	--	--	--	7.2	7.2
C_1N	46	28	- 4.7	--	--	--	7.0	0.50
C_2N	22	18	- 1.0	--	--	--	7.3	1.2
S_1O	360[2]	109	- 65.2[2]	584	272	--	7.3	7.2
S_2O	68	61	- 1.8	584	164	--	7.3	7.2
S_1N	317	734	+108.4	732	1052	--	8.3	0.20
S_2N	275	677	+104.5	660	980	--	8.4	0.20
D_1O	63	43	- 5.2	432	172	--	7.3	7.2
D_2O	68	54	- 3.6	356	140	--	7.3	7.1
D_1N	196	406	+ 55.1	468	832	--	7.5	0.60
D_2N	209	368	+ 41.3	584	--[2]	--[2]	8.1	1.4

[1]Sediments were mixed in situ until resuspended. Four days elapsed between initial and final measurements to allow for settling. (+) signifies release from sediments. (-) signifies sediment uptake.

[2]Contaminated.

algae samples were collected at three depths; just below the surface, middle depth, and just off the bottom using a one liter Kemmerer bottle. During portions of June and July 1979, after no difference in species composition and abundance at different depths was observed, an integrated phytoplankton sampler was used to collect phytoplankton. The integrated phytoplankton sampler consisted of a length of Tygon tubing of one inch diameter and weighted at one end. The open tube was lowered to the desired depth, then the upper end was plugged and the tube carefully removed from the water. Using such a tube, a representative sample of the water column was obtained. The integrated phytoplankton sampler was used during the remainder of the study, except when extensive algal blooms occurred. During algal blooms in which phytoplankton were concentrated at the lake surface, the integrated sample method was inappropriate.

Water samples were placed in 250 ml plastic containers and packed in ice while being transported to the laboratory. Samples were either examined fresh or preserved in Lugol's iodine solution for later examination.

Laboratory methods. Phytoplankton were identified to genus using a light microscope. Prescott (1977) was used to key specimens. Algal abundance was determined using a Sedwick-Rafter counting cell. A one cubic centimeter aliquot was taken from each sample and placed in the cell. The numbers of each genus of algae were tabulated for ten randomly-selected fields examined under low power. The number of organisms per liter was calculated using the formula:

$$N = \frac{m \times \frac{1000}{An} \times v}{V}$$

Where: A = area of field examined in nm^2.
n = number of fields counted.
m = total number of organisms of a particular species in n field.
v = measured volume of the concentrated sample in cubic centimeters.
V = volume of water strained to obtain v.
N = number of organisms per liter.

In most cases the number of phytoplankton present were great enough that neither straining water samples (using a Juday Plankton Trap) nor concentrating samples by centrifuging was necessary, (D.G. Frey, pers. comm.).

Methods which measure abundance using numerical counts may bias results in favor of taxa that are small and numerous. For example, when algae are counted using the Sedwick-Rafter cell, a large alga will also count as one unit. Most of the blue-green species that commonly occur in eutrophic waters such as *Anabaena*, *Aphanocapsa*, *Oscillatoria*, and *Microscystis* are filaments or large colonies, and thus the abundance and dominance of these genera may be underestimated using this method. Fogg (1975) compares the three methods most commonly used to estimate abundance (cell counts, measures of cell surface areas, and cell volume) and concluded that all three methods correlated well with standing crop and rates of photosynthesis as to give equally useful pictures of abundance.

Results. Table 2-21 lists the genera identified and lists the percentage frequency for each taxonomic group for each sample date. A total of 56 genera were identified including 34 genera of green algae (Chlorophyta), 13 genera of blue-green algae (Cyanophyta), 6 genera of Chrysophyta, which include the diatoms, and 1 genus of dinoflagellates (Pyrrophyta). In addition to the sample dates listed, samples were examined on March 2, 1979, while the lake was still ice covered. While samples from this date were not examined quantitatively, it was noted that the phytoplankton consisted primarily of sparse populations of Stephanodiscus, Oocystis, Palmellococcus, and Melosira.

The genera listed in Table 2-21 are found in a wide range of aquatic environments. However, many are characteristic of eutrophic conditions. These include Microcystis, Oscillatoria, Coelastrum and Stephanodiscus. For example, Palmer (1969) examined reports from 165 authors and developed a pollution index using indicator genera for rating water samples contaminated by high organic pollution. Genera and species were assigned a pollution index number ranging from 1 for genera moderately tolerant to organic pollution, to 6 for highly tolerant genera. Oscillatoria, a major component of an algal bloom which occurred at Cedar Lake in mid-August, is rated at 5. Scenedesmus, which was consistently found in Cedar Lake samples at low population levels, is also rated 5. Microcystis, which dominated the phytoplankton of Cedar Lake during most of the summer months, is a well documented nuisance alga which is characteristic of eutrophic conditions in hard water lakes (Fogg 1975; Tarapchak and Stoermer 1976).

Figure 2-40 illustrates changes in total phytoplankton abundance and the representation of each major phytoplankton group for Sampling Site A in 1979. There was no significant difference found among the phytoplankton populations for Sites A, B, or C, or at the various depths sampled. The shallowness of the lake and the high degree of mixing which occurs account for the homgeneity of Cedar Lake's phytoplankton community

Figure 2-40 shows that Cedar Lake exhibits a typical pattern of productivity changes for shallow eutrophic lakes in temperate regions. The low temperatures and reduced sunlight in winter and early spring keep populations low until the water temperatures rise and the phytoplankton population undergoes rapid growth. Population levels may vary widely in the summer due to a variety of factors such as nutrient availability, morphological characteristics of the lake, weather conditions, biological interactions, and other conditions. Often there are algal blooms, rapid increases in the population of one or several species, in late summer. Such a bloom occurred during the second week of August, 1979 at Cedar Lake and consisted of a number of blue-green species, primarily Microcystis and Oscillatoria. Such blooms are a major concern of Cedar Lake residents and users.

The changes in algal species composition seen in Cedar Lake are common for eutrophic lakes. Temperature and light conditions favor diatoms and green algae in the spring. Blue-green species rapidly take over as sunlight and water temperatures increase. Often, the number of green algal species and individuals do not actually decline, but rather are unable to keep up with the rapid rate of reproduction by the blue-green species. Figure 2-41 illustrates the changes in the percent species composition by volume for the sampling period. Blue-green species dominate the phytoplankton quite early, constituting the majority of counts by May 10. In July and August blue-greens represented over 70% of the counts. A large majority of the blue-green population was the nuisance alga Microcystis. Since colony counts were made of many of the blue-green species, their domiance is probably underestimated.

The algal populations of the inflowing and outflowing streams of the lake were also monitored. The majority of these streams are ephemeral. Streamflow was of short duration in most cases, even in the spring, and large phytoplankton populations did not develop. Samples showed sparse populations of primarily pennate diatoms, a characteristic flora for small streams. More sluggish areas near the lake, such as the outflow at Cedar Creek, showed phytoplankton composition which mirrored those of the lake.

Visual observations were made of areas other than the sampling sites for local changes in phytoplankton populations. For example, as early as June 6, 1979, small mats of dead algae, primarily Microcystis, appeared on the northern shore of the lake, concentrated there by wind action. Other mats of dead algae appeared along the shores of the south and middle basins of the lake on June 22. Examination of these mats showed that they consisted primarily of the green filamentous alga Cladophora. This alga apparently was attached to sand and gravel bottom of shallow areas of these basins and died off as increasing turbidity reduced light penetration below that needed for survival.

Discussion. There are a number of factors which may influence the species composition and abundance of phytoplankton in lakes. The more important of these include water chemistry parameters, such as nutrient availability and alkalinity, water temperature, biological factors, and physical factors such as depth, turbidity, and the nature of the substrate. Although the effects of each of these factors cannot be quantified for Cedar Lake, they will be discussed here to provide a better understanding of phytoplankton dynamics.

Nitrogen and phosphorus concentrations are of major importance in determining the trophic status of a lake. Vollenweider (1968) indicates that blue-green algae tend to be abundant in lakes where the concentration of these two elements exceeds 10 ug/l P and 200-500 ug/l N in the spring. Available phosphorus (SRP) and inorganic nitrogen concentrations in Cedar Lake exceeded these levels throughout the project period. However, the relationship between phosphorus and nitrogen is often more critical to consider than absolute concentrations.

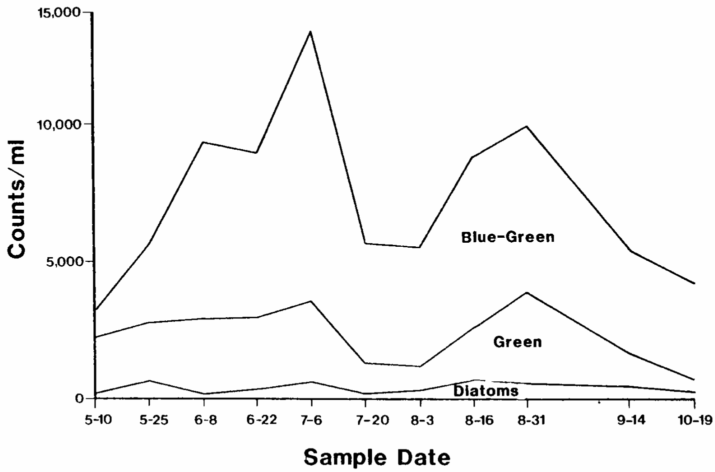


Figure 2-40. Phytoplankton abundance and composition for Cedar Lake Site A in 1979.

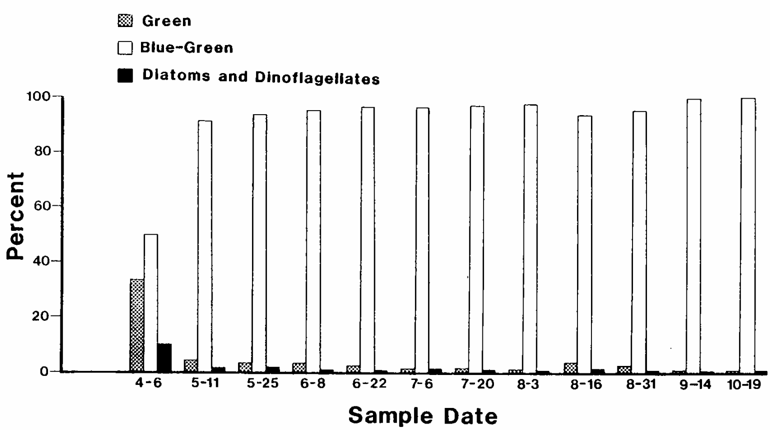


Figure 2-41. Phytoplankton species composition changes (by volume) for Cedar Lake in 1979.

Changes in the N:P ratio in lake water can account for much of the oscillation in algal species abundance and composition within lakes. Smith (1983) reports a dramatic tendency for blue-green algal blooms to occur when epilimnetic N:P ratios fall below about 29:1 by weight, and for blue-green algae to be rare when the N:P ratio exceeds this value. The N:P ratio in Cedar Lake was below the 29:1 ratio for much of the summer of 1979 (see Table 2-24). Blue-green species can have a competitive advantage over other algal species because of the ability of some species to store both phosphorus and nitrogen and to fix nitrogen. Nitrogen and phosphorus reserves in blue-green species can suffice for several cycles of cell division after exogenous supplies have been exhausted (Fogg 1975). Furthermore, the ability to fix nitrogen makes some blue-green species superior nutrient competitors under conditions of nitrogen limitation. Nitrogen fixation occurs primarily in those blue-green species possessing heterocysts such as Anabaena, Aphanizomenon, and Gloeotrichia (Fogg 1975; Provasoli 1969; Stewart 1969).

There are a number of other factors which can give the blue-greens a competitive edge over other algal species. Many blue-green algae contain gas vacuoles which make them more bouyant. In very turbid lakes, such as Cedar Lake where the photic zone may extend for less than a meter, the added bouyancy due to gas vacuoles can allow blue-greens to dominate this zone while at the same time, shade out species below (Fogg 1975). This advantage may be less dramatic in Cedar Lake where near-constant water circulation can bring other algal species up into the photic zone for certain periods of time.

Other species such as Cladophora, which were found attached to pilings and the sand and gravel bottom in the littoral zone of Cedar Lake, probably undergo light limitation once turbidity increases. Evidence to support this in Cedar Lake is from a Cladophora die-off in June.

Summary. THe phytoplankton of Cedar Lake exhibit an expected pattern of seasonal population growth and species composition for a shallow eutrophic or hypereutrophic lake. The algal population is dominated by blue-green species during most of the growing season. Algal productivity is high, but total productivity is probably limited by a shallow photic zone. Increasing the depth of the photic zone by reducing turbidity, without at the same time reducing nutrient concentrations, could stimulate algal productivity to higher levels than have been experienced in the past. This possibility should be closely examined before selecting a restoration program.

2.6.2 Macrophytes

Because of the turbidity of its waters and nearly complete development along its shoreline, Cedar Lake contains few macrophytes. This has not always been the case; historical records and photographs show that Cedar Lake was a suitable habitat for many species of aquatic plants until the 1950's. These plants produced habitats for desirable species of fishes such as the northern pike (Esox lucius). Increased turbidity was primarily responsible for the demise of the macrophyte populations in Cedar Lake. As the amount of light reaching the lake bottom decreased, aquatic plants, particularly submergent species, were unable to germinate and grow.

Only a single emergent macrophyte species is common in the lake, Nuphar advana or spatterdock. It is found in small patches on the western shoreline of the lake. No emergent macrophytes were observed on the eastern side of the lake. Figure 2-42 shows the distribution of spatterdock in Cedar Lake. Coontail (Ceratophyllum demersum), a submergent species, is found at a single shallow locality in the north basin. It's distribution is also shown in Figure 2-42.

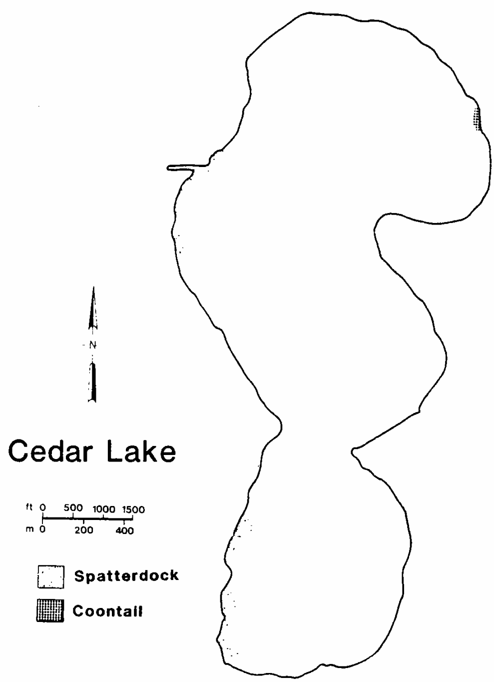


Figure 2-42. Distribution of macrophytes in Cedar Lake in 1979.

Because the large wetland areas adjacent to the lake contain a diverse assemblage of macrophytes, other species may establish themselves along the lake shoreline. Sagittaria latifolia, an emergent, and duckweek (Lemna) were found along the lakeshore, near the inlets from wetland areas, but neither were common. Both are indicative of disturbed systems.

Estimates of the area of the lake covered by vegetation total approximately one acre, or less than 1% of the total area of the lake. Identification of macrophytes was determined using Prescott (1969).

2.6.3 Fish

Population Studies. Surveys of the fish populations of Cedar Lake have been conducted by the Indiana Department of Natural Resources (DNR) in 1964, 1969, 1971, 1974, 1976, and 1977. A survey was conducted in August of 1979 as part of the Cedar Lake Restoration Study. The results of the 1976 survey, which include a fisheries management report and the most recent survey are included in Appendix D.

Information from these reports and other historical data gathered on the lake's fisheries show that species composition has undergone extensive changes in the last 30 years. Although quantitative studies are not available prior to 1964, the 1964 fisheries survey reports a species composition which included northern pike, largemouth bass, and white crappie. In the 1950's fishermen noted changes in the fish population of Cedar Lake. Carp, bullheads, and other rough fishes became increasingly common and more desirable fishes, largemouth bass, bluegills, and northern pike diminished or disappeared. Algal blooms became common during the 1950's and emergent and submergent vegetation began to disappear.

In 1964 the DNR conducted it's first fisheries survey in Cedar Lake. Finding the situation unsatisfactory, the DNR recommended that the entire fish population be eradicated and that the lake should be restocked with game species, largely bluegill and largemouth bass. In 1966 such a renovation was completed. Approximately 2300 gallons of rotenone were applied to the lake and neighboring marshes, following which, the lake was restocked with game fishes. Because of several factors - continued eutrophication of the lake, a series of severe winters that resulted in fish kills, and the migration of rough fishes from Lake Dalecarlia via Cedar Creek, desirable fish populations have dwindled in recent years.

Table 2-22 shows the five most numerous fish species in Cedar Lake for five different surveys and how species populations have flucuated. The renovation of the lake in 1966 was responsible for the disappearance of yellow perch. The dominance of largemouth bass and bluegill populations in 1969 was the product of stocking efforts by the DNR. Rough fishes such as the gizzard shad and carp established themselves in the early 1970's, probably gaining entrance into the lake by way of Cedar Creek. In 1976, a severe winter produced a thick ice cover on the lake which, along with heavy snows, reduced oxygen levels in the lake and killed many fish

Table 2-22. Relative abundances of Cedar Lake fish for five different fisheries surveys.

Survey Year	1964		1969		1974		1976		1979	
	Species	%	Species	%	Species	%	Species	%	Species	%
most abundant	yellow perch	46.6	largemouth bass	26.3	gizzard shad	79.5	gizzard shad	61.6	black crappie	42.6
2nd	brown bullhead	18.5	bluegill	22.3	carp	10.3	carp	13.2	carp	38.9
3rd	white crappie	12.6	brown bullhead	18.8	brown bullhead	3.8	goldfish	7.6	channel catfish	9.5
4th	carp	7.6	carp	14.4	northern pike	2.1	bluegill	6.5	bluegill	1.0
5th	orange-spotted sunfish	2.9	black bullhead	12.5	channel catfish	1.5	black crappie	6.3	northern pike	1.0
Total Percent Represented		88.2		94.2		95.6		93.0		

including most of the gizzard shad population. Since then, black crappie and carp have been the most abundant fishes in Cedar Lake. In the 1979 survey, carp accounted for 38.9% by number of all fish sampled but over 80% by weight. Plankton feeding and filter feeding fishes such as carp are able to dominate the lake because sight feeders, such as largemouth bass, cannot locate food as successfully in highly turbid waters.

In a fisheries management report issued by the Fisheries Division of the DNR in 1976, it was recommended that additional attempts at restocking or renovating Cedar Lake would not be successful until water quality, particularly turbidity, was improved. The report also recommended that the two dams downstream from Cedar Lake on Lake Dalecarlia be altered to prevent further migration of rough fishes and that channel catfish be supplementally stocked into Cedar Lake. Improvements have been made to the spillway on the east end of Lake Dalecarlia, however a fish screen was not included because it would have interfered with discharge from the lake. The fisheries division has begun to stock Cedar Lake with channel catfish and the recent survey indicates that these efforts have been successful to date.

<u>Metals in Fish</u>. During the 1979 fisheries survey conducted by our research team and the Department of Natural Resources, some of the fish captured in gill nets were later analyzed for metals content. Fish species can accumulate metals in concentrations higher than ambient levels in waters or sediments. Because of high levels of metals measured in Cedar Lake's sediment, expecially zinc, fish tissues were analyzed. Also, biologists may use information on

metals content of fish to ascertain tolerance levels, which can be used to make determinations of the causes of fish kills (Anderson 1972).

Four species were sampled: carp, catfish, crappie, and northern pike. Several individuals of each species were wrapped in aluminum foil and packed on ice. Upon arrival at the laboratory, liver, kidney, gill, and fillet tissues were excised from each fish. Crappie kidneys were not taken. Tissue samples from individuals of species were combined according to tissue type, and then were freeze-dried and digested in nitric acid. Metal determinations were made by atomic adsorption spectrophotometry.

Results are given in Table 2-23 where concentrations of four metals in various tissue types are presented for each species of fish. Copper and zinc occurred in concentrations that were easily detected. Pike and carp showed highest concentration of these metals. Highest levels were found in the liver tissues and lowest values occurred in the edible fillets.

Table 2-23. Metals concentration (ug/g) in fish tissue sampled at Cedar Lake in 1979.

Species	Organ	Copper	Zinc	Lead	Cadmium
Carp	liver	10	1485	1.0	1.0
	kidney	10	53.6	1.0	1.0
	gill	5	1198	1.0	1.0
	fillet	1	36.4	1.0	0.5
Catfish	liver	13	136.2	1.0	0.5
	kidney	4	57.4	1.0	1.0
	gill	3	70.3	1.0	0.5
	fillet	1	18.3	1.0	0.5
Crappie	liver	13	111.3	1.0	0.5
	kidney	--	--	--	--
	gill	5	64.9	1.0	1.0
	fillet	1	22.8	1.0	0.5
Pike	liver	23	1061	1.0	0.5
	kidney	5	425	1.0	0.5
	gill	3	815	1.0	1.0
	fillet	1	21	1.0	0.5

Lead and cadmium levels were at the detection limits for the instrument. For these cases a maximum value was determined from calculations based on sample weight and digestion solution volumes. Using these calculations, cadmium levels do not appear to be high compare to other eutrophic lakes. Murphy et al. (1978) report values for various fish species from Palestine Lake, Indiana of 0.06

ug/g to 8.0 ug/g. Values reported by Mathis and Kevern (1975) for whole body concentrations average 0.05 ug/g.

Cadmium is toxic to man and cases reported in the literature (Frant and Kleeman 1941) indicate that human consumption of 1.3 to 3.0 mg of cadmium results in toxic effects. (This amounts to 4.3 to 10.0 kg of carp fillet taken from Cedar Lake). Because of the toxic nature of cadmium, further study to elucidate exact low-level values would be advisable.

Like cadmium, lead values were at or below the detection limits for our methods. Maximum possible concentrations in the species analyzed (based on calculations by sample weight) were less than 1.0 ug/g. Rolfe et al. (1977) report lead concentrations in fish between 1.4 and 4.1 ug/g. Mathis and Kevern (1975) report mean lead values of 0.32 ug/g in fillets. Mathis and Cummings (1971) report concentrations ranging from 0.57 to 0.64 ug/g for fish from the Illinois River.

Copper concentrations reported by Kelso and Frank (1974) in various fish taken from Lake Erie ranged from 1.29 to 1.56 ug/g. Brooks and Rumsey (1974) reported fillet concentrations of copper from 0.04 to 0.95 ug/kg and state that concentrations within these ranges do not represent a public health problem. The upper range of concentrations reported by Brooks and Rumsey is close to the values for fillet portions from all species sampled in Cedar Lake.

Zinc concentrations in Cedar Lake fish are higher than concentrations of other metals analyzed. For the most part, zinc in fillets falls below values reported in the literature for polluted lakes. Lande (1977) found concentrations of 80 ug/g in fish from a contaminated fjord in Norway. Mathis and Cummings (1973) found a maximum of 40 ug/g in fillet tissue of fish taken from a contaminated river system. Giesy and Wiener (1977) reported high whole fish levels in excess of 294 ug/g.

Generally, zinc levels in fish fillets analyzed from Cedar Lake fall within the range of average concentrations for whole fish from relatively uncontaminated aquatic ecosystems (48-173 ug/g) (Lucus et al. 1972; Harve et al. 1973; Kelso and Frank 1974; Giesy and Wiener 1977). Zinc was lowest in fillet tissue. Concentrations in the liver and gill sections were found to be higher.

The distribution of zinc by species did not suggest that the top carnivorous species (pike) accumulated more than others. In fact, highest zinc concentrations were found in carp. Copper, on the other hand, was highest in pike and lowest in carp.

<u>Summary</u>. Lead and cadmium concentrations in various tissues of fish from Cedar Lake were at or below detection limits. While lead concentrations in sediments are high, there is little apparent bioaccumulation. Mathis and Kevern (1975) showed that lead accumulation in freshwater fish did not correlate with body size and fish age. Lead does not have nutritional value and is not accumulated as biomass, but becomes concentrated in specific

$$\log[\text{chl } \underline{a}] = 1.583 \log[P] - 1.134$$

This equation is the regression line through Sakamoto's data points for chlorophyll and total phosphorus in water taken from lakes and ponds in May, June, and September (Sakamoto 1966).

Table 2-24. Representative N:P ratios for Cedar Lake in 1979.*

Date	N:P
April 6	700:1
May 25	34:1
June 8	35:1
June 22	5:1
August 16	8.8:1
September 14	15:1
October 19	9:1

*N includes $NH_4 + NO_3 + NO_2$; phosphorus includes SRP.

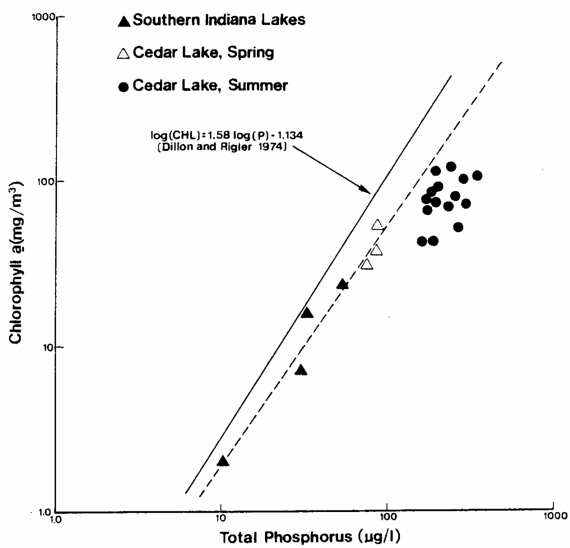


Figure 2-43. Chlorophyll a vs. total phosphorus as plotted against Sakmoto's data points.

Plotted on the graph are chlorophyll *a* and phosphorus values for four southern Indiana lakes (Preston 1979) and 1979 Cedar Lake values. The early spring values for Cedar Lake and those for the other lakes fall on a line similar to that of Dillon and Rigler's. Cedar Lake values from the summer appear to diverge from this line, suggesting that chlorophyll *a* concentrations (i.e., productivity) were not high enough to fall on the line. This implies that phosphorus is not a limiting nutrient in Cedar Lake during the summer months.

2.7.3 Other Limiting Factors

The shallow depth of the trophogenic zone, the upper stratum of a lake in which photosynthesis occurs, may also limit phytoplankton productivity in Cedar Lake. This zone was very shallow as approximated by Secchi disc transparency depths which ranged between 21cm and 59cm. It is likely that a decrease in the turbidity within Cedar Lake without a concurrent decrease in nutrient concentrations would result in greater productivity

Besides resuspending particulate matter from the sediments to the water column, turbulent wind conditions also create circulation patterns within Cedar Lake which provide for vertical mixing throughout the water column. This can effectively restrict the length of time which phytoplankton can remain in the trophogenic zone. This limitation may be offset by the fact that vertical mixing also allows algal cells in deeper water to circulate up to the trophogenic zone.

2.7.4 Summary

Most of the evidence gathered for Cedar Lake suggests that nitrogen, particularly the nitrate fraction, is a limiting nutrient for phytoplankton productivity during most of the summer growing season. The shallow depth of the trophogenic zone may also limit photosynthetic activity.

2.8 WETLANDS

2.8.1 History

As mentioned briefly in Section 1.3, there are two wetlands connected by streams to Cedar Lake. We have little informatiuon concerning the 5.7 ha (14 acre) wetland that lies at the northern edge of the lake other than the fact that some filling has taken place and that water levels in the wetland and the lake are maintained at the same elevation by a small stream connnecting the two.

The other wetland, 163 ha (403 acre) Cedar Lake Marsh lying along the south end of the lake, has been identified by Goodwin and Neiring (1975) as the "largest continuous marsh in the state." Lindsey et al. (1969) suggest that the wetland is intrinsically suited for a wetland preserve.

Cedar Lake Marsh was a part of Cedar Lake until the lake level was lowered in the early 1870's. Since that time, the wetland has been isolated from the lake by a strip of filled land running along the south shore of the lake. Residences have encroached upon the wetland and additional filling has occurred at many locations. A small rubbish dump extends into the south end of the wetland although it is reported to have been closed down. From around 1940 to 1960, 80 acres of the northwest section of Cedar Lake Marsh were artifically drained by channelizing the inlet stream which flows through that section. The area was then cultivated and farmed (R. Howkinson, Cedar Lake realtor, pers. comm).

2.8.2 Current Studies

Our work in Cedar Lake Marsh concentrated on two areas: 1) understanding the present role of the marsh, and 2) assessing the future role the marsh might have in any lake restoration effort. The latter will be discussed in greater detail in Section 6.3.5.

Vegetation Mapping. In order to understand the present role of the marsh we first mapped the wetland. The mapping was accomplished using black and white aerial photographs obtained from the Agricultural Stabilization and Conservation Service (ASCS) and the Northwestern Indiana Regional Planning Commission (NIRPC). Mapping the major wetland vegetation at this scale enabled us to examine vegetation patterns and provided some understanding of flow through the wetland and into Cedar Lake (Figure 2-44).

Hydrology. Approximately one-half of Cedar Lake's drainage basin drains into Cedar Lake Marsh. Two small streams carry this drainage from the wetland into Cedar Lake although both were dry periodically throughout the summer. To better understand the hydrologic connection between the wetland and the lake, soil cores were taken in August, 1979 from two sites in the filled strip separating the wetland and the lake and from two sites in the wetland itself. The cores in the filled area were characterized by sandy fill material from 0-4 feet deep and hard gray clay from 4-7 feet. The water table was 5-6 feet below the ground surface. The wetland cores consisted of organic material from 0-5 feet deep and hard gray clay from 5-7 feet.

The clay soils at 4 to 5 feet below the surface in both the filled and wetland sites are probably old lake sediments deposited prior to the lake level drawdown in the early 1870's. The presence of these low permeability soils along with the location of the water table suggest that there is only limited hydraulic movement of groundwater between the lake and the wetlands during the summer months.

Drainage ditches constructed in the wetland are readily observable on the aerial photographs. These ditches channel water through the wetland thereby reducing the retention time of water flowing through the wetland. If the retention time is significantly reduced, then the ability of the wetland to remove silt and nutrients from runoff prior to its reaching the lake is similarly affected.

The aerial photographs indicated this channeling of water may be most severe on the eastern portion of the wetland - suggesting that runoff from the golf course and adjacent farmland may reach the lake more rapidly than is desirable. On the west side of the wetland a small stream carrying agricultural runoff is high in nutrients. The data appear to indicate that the wetland does assimilate some of these nutrients prior to their reaching the lake, at least during the growing season.

In addition to these uses the wetland serves as a resting area for waterfowl and provides recreational activity for local sportsmen.

Phosphorus Dynamics. Phosphorus dynamics in wetland soils were studied using a batch test (Robert H. Kadlec, pers. comm.). Seven centimeter-diameter acrylic plastic tubes were inserted into the wetland soil. The overlying water was pumped out using a hand pump. Care was taken not to remove or disturb the soil surface. Lake water of known SRP concentration was gently added to the tubes to the previous water level. The soil in one tube was left undisturbed while that in the other tube was agitated to a depth of 5 cm to allow for resuspension. After 24 hours, water samples were withdrawn and analyzed for SRP. The data are presented in Table 2-25.

Table 2-25. Wetland batch test results

Sample	SRP (ug/l)
Make-up Lake Water	30.4
Undisturbed tube	19.6
Disturbed tube	1078.9

Results indicate that if the Cedar Lake Marsh sediments are not disturbed (resuspended), they may remove SRP from water passing over them. In the batch test, 36% of the SRP was removed in 24 hours. However, it must be noted that water residence time, oxygen content, and rate of flow are all important factors controlling the rate of phosphorus removal. Under anoxic conditions or when sediments are disturbed, SRP can be released from the sediments. Disturbed sediments released a significant amount of SRP in the single test conducted.

2.9 SEPTIC TANK LEACHATE DETECTION

Prior to 1977, leachate from on-site septic tank disposal systems was strongly suspected of contributing major loadings of phosphorus to Cedar Lake. With the completion of the wastewater collection system, all but a few isolated on-site systems were

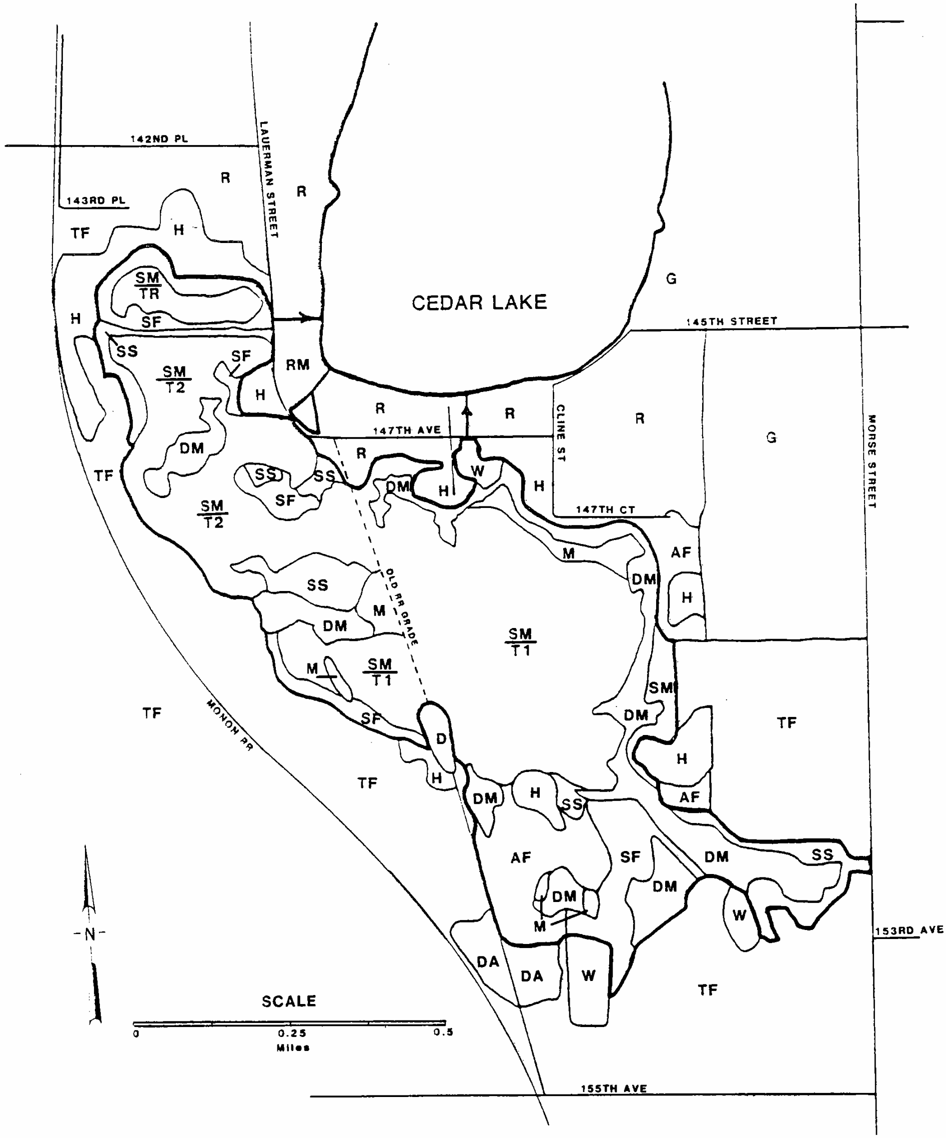


Figure 2-44. Generalized vegetation map of Cedar Lake Marsh.

LEGEND

AF - Abandoned field

D - Dump

DA - Automobile dump

DM - Deep marsh

G - Golf course

H - Hardwoods

M - Flooded meadow

R - Residential

RM - Marina

SF - Seasonally flooded

SM - Shallow marsh

SS - Shrub swamp

T - Cat-tail community

TF - Tilled field

TR - Cat-tail/swamp rose community

W - Open water

1 - Dense vegetation

2 - Open water prevalent

Figure 2-44 (cont.)

retired. Because of these previous loadings, an effort was made to determine whether the inactive on-site drain fields or the remaining active on-site systems were continuing to leach phosphorus into Cedar Lake.

Of the field techniques available, dye studies were not practical since most of the systems of interest were inactive, and extensive water sampling was considered too expensive and time consuming. An alternative method was to use a septic leachate detector (SLD), commonly known as a "septic snooper", to aid in the location of septic leachate plumes in Cedar Lake. This technique has been successfully used in other studies (Kerfoot and Skinner 1981; U.S. EPA 1979).

2.9.1 Septic Leachate Detector

The Septic Leachate Detector is an instrument that is capable of detecting effluents of septic systems by responding to a combination of conductivity changes and fluorescense. The SLD used at Cedar Lake was an ENDECO (Environmental Devices Corporation, Marion, Massachusetts) Type 2100 Septic Leachate Detector System (Figure 2-45). The instrument and its theory are described by excerpts from the manufacturer's operation manual as reported in (Peters 1982):

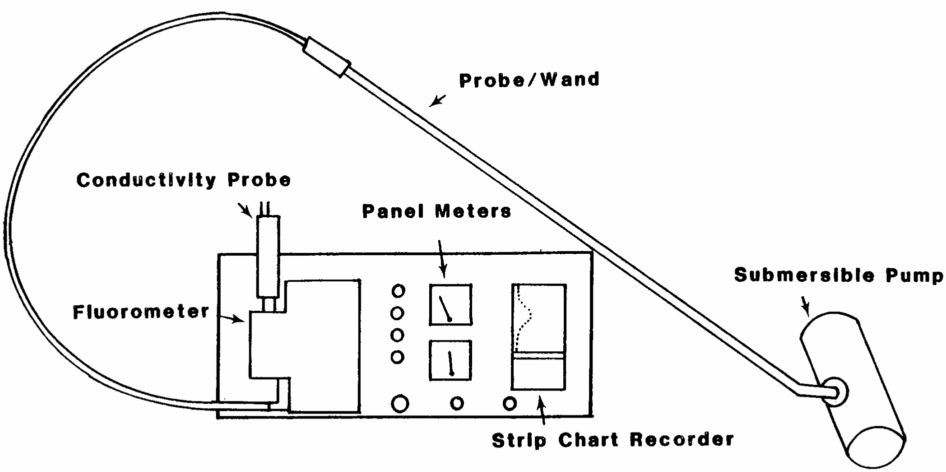


Figure 2-45. Schematic diagram of the Endeco Type 2100 Septic Leachate Detector System.

The ENDECO Type 2100 Septic Leachate Detector System is a portable field instrument that monitors two parameters, fluorescence (organic channel) and conductivity (inorganic channel). The system is based on a stable relationship between fluorescence and conductivity in typical leachate outfalls. Readings for each channel appear visually on panel meters while the information is recorded on a self-contained strip chart recorder. Recording modes are selectable between individual channel outputs or a combined output. The combined output is the arithmetic result of an analog computer circuit that sums the two channels and compares the resultant signal against the background to which the instrument was calibrated. The resultant output is expressed as a percentage of the background. Also, the combined recorded output is automatically adjusted for slow background changes. The system can be operated from a small boat enabling an operator to continuously scan an expansive shoreline at walking pace and, through real time feedback, effectively limit the need for discrete grab samples to areas showing high probability of effluent leaching. Expensive laboratory time for detailed nutrient analysis is greatly reduced while survey accuracy is increased substantially.

...The unit [is] powered by a standard 12-volt automotive battery. The plug-in, flow-through conductivity cell is in series with the fluorometer. The probe/wand houses a marine-type centrifugal pump. Discrete samples may be drawn directly from the instrument discharge for subsequent laboratory analysis...

Wastewater effluent contains a mixture of near UV florescent organics derived from whiteners, surfactants and natural degradation products that are persistent under the combined conditions of low oxygen and darkness...

Aged effluent percolating through sandy loam soil under anaerobic conditions reaches a stable ratio between the organic content and chlorides which are highly mobile anions. The stable ratio (cojoint signal) between fluorescence and conductivity allows ready detection of leachate plumes by their conservative tracers as an early warning of potential nutrient break-throughs or public health problems.

The Septic Leachate Detector System consists of the subsurface probe, the water intake system, the logic analyzer control unit, panel meters and the strip chart recorder....

The probe/wand is submerged along the shoreline. Background water plus groundwater seeping through the shore bottom is drawn into the subsurface intake of the probe and is lifted upwards to the analyzer unit by a battery operated, submersible pump.

Upon entering the analyzer unit the solution first passes through the fluorometer's optical chamber where a continuous measurement is made of the solution's narrow band response to UV excitation. The solution then flows through a conductivity measurement cell. An electrode-type conductivity/thermistor probe continuously determines the solution's conductivity. The solution exits the conductivity cell directly to the discharge where discrete samples may be collected if indicated by the response of the leachate detector. Both parameters are continuously displayed on separate panel meters. Zero controls are provided for both parameters (organic and inorganic) to enable "dialing out" the background characteristics to provide maximum sensitivity, as well as enhancing the response caused by a suspected abnormality. Span controls are also provided to control the sensitivity of each parameter separately during instrument calibration. This is helpful in determining relative concentrations of leachate outfalls.

The signals generated and displayed on the panel meters are also sent to an arithmetic/comparator analog computer circuit designed to detect changes in the ratio of organics and inorganics typical of septic leachate. The output of this circuitry is recorded continuously on a strip chart and is the key indicator of a suspected leachate outfall. However, isolated increases in either parameter may be cause for concern and should be sampled for analysis for other potential forms of nutrient pollution.

2.9.2 Field Methods

The SLD used on Cedar Lake was on loan from the U.S. Environmental Protection Agency, Region V, Chicago. Mr. Jack Kratzmeyer of EPA's Environmental Impact Section operated the unit during the survey with the assistance of project personnel. The SLD was used to locate areas with characteristics found in inadequately treated wastewater. These suspect areas will be referred to as plumes.

The survey was limited to shoreline areas known to have active on-site septic tank disposal systems and those areas, primarily the southern shore of the lake, having stream discharges (Figure 2-46). An initial scan of these areas was made on July 6, 1982 to locate possible leachate plumes. Plumes detected during this initial shoreline scan as indicated by positive SLD responses, were scanned again the following day. If a plume was detected on both days, water samples were collected in the plume from the SLD discharge port. Fifteen of the strongest suspected effluent plumes were sampled and analyzed for fecal coliform bacteria and soluble reactive phosphorus (SRP). Coliform samples were anlayzed by the Lake County Health Department. SRP samples were returned to the laboratory and analyzed by the methods described in Appendix A.

Because sources other than septic tank effluent can also produce positive detector responses, samples were collected at beaches and where streams and channels enter the lake for purposes of comparison. Baseline conditions for the parameters analyzed were determined from two background samples.

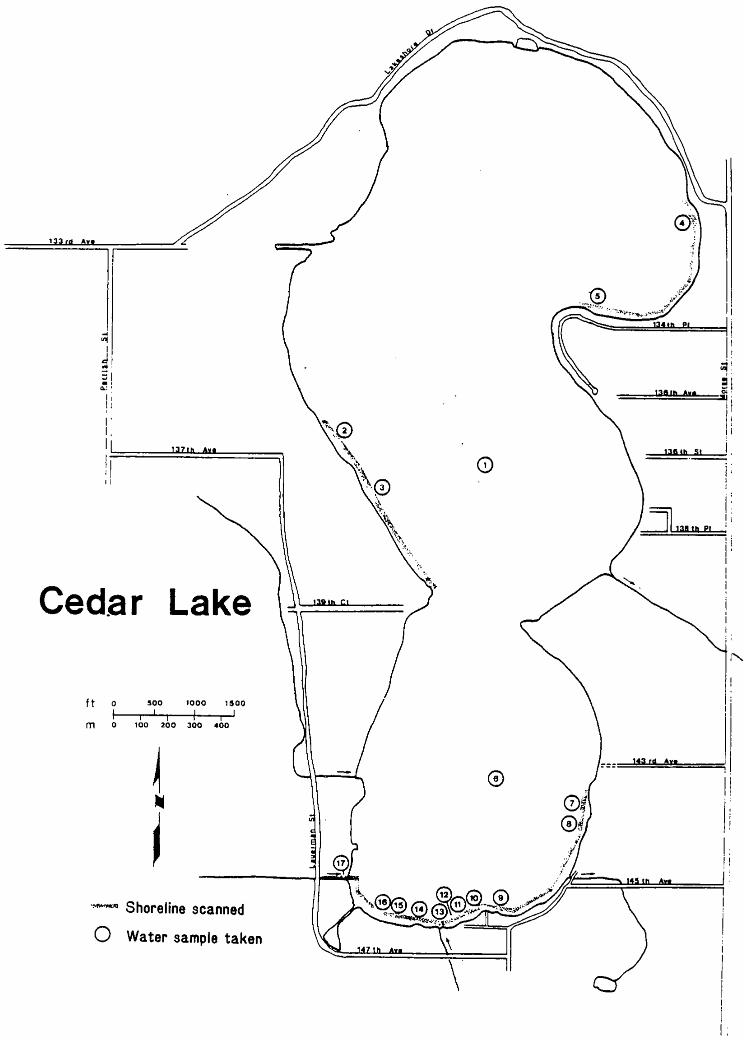


Figure 2-46. Septic leachate detector survey areas.

During all scans the detector's meters were adjusted to maximum sensitivity. The alternate method of senitivity control, described in the manufacturer's owner manual, supposedly allows for quantification of the percent effluent at the point sampled using the combined recording (EDC 1980). However, this method of sensitivity control is based on the theory that there exists a "stable ratio" between flourescence and conductivity in domestic wastewater. Experience indicates that this is not always true. Adjusting the meters to maximum sensitivity, as done in this survey, puts greater emphasis on operator interpretation of recorded signals but is less likely to miss a typical effluent plume.

The instrument was set to record data on the combined mode. This setting provides automatic adjustment for changing background levels of fluorescence or conductivity but still records the short-term increases indicative of localized sources such as effluent plumes. It also permits the operator to pay greater attention to observing possible sources and to recording his observations.

2.9.3 Results

Of the seventeen plumes sampled, only one (Sample Site 17) had any fecal coliform bacteria present (Table 2-26). This same sample also had the highest concentration of SRP. Site 17 receives surface discharge from Cedar Lake Marsh and this probably accounts for the positive SLD response. Naturally occuring organic materials released from decomposing vegetation have been shown to cause increases in fluorescence over the same wavelength range as do the brighteners from cleaning products that the SLD is calibrated to detect. The SLD used is unable to distinguish between these sources.

Table 2-26. Results of water quality analyses from suspected septic leachate plumes.

Sample No.	Fecal Coliform (#/100 ml)	SRP (ug/l)
1 (background)	0	27
2	0	23
3	0	9
4	0	2
5	0	3
6 (backgound)	0	38
7	0	34
8	0	45
9	0	50
10	0	39
11	0	29
12	0	45
13	0	30
14	0	23
15	0	25
16	0	14
17	30	117

Other than Sample 17, SRP concentrations ranged only slightly above and below the background concentrations measured in the middle of the lake.

Of the 17 positive SLD responses sampled, 3 were characterized by comparable increases in both conductivity and fluorescence and 14 were characterized by significant increases in conductivity only. See Figures 2-47 through 2-50 for examples of SLD strip charts and recorded plumes.

2.9.4 Discussion

The SLD is designed to detect septic leachate plumes containing organic and inorganic materials in concentrations above background lake conditions. A positive response by the unit indicates that a plume may be present. Such responses should be reconfirmed on two or three successive days to increase the reliability that a plume is present. The absence of a positive SLD response does not necessarily mean that septic systems are not leaching into the lake. The following conditions can all contribute to real plumes not being detected by the SLD:

1. Windy conditions which disperse the plume.

2. Variable loading to the septic system, for example, on weekends or seasonally. If scanning is not conducted while the system is in use, no plumes may be present.

3. Fluctuations in lake levels can slow or even reverse normal groundwater flow, temporarily eliminating leachate emergence at a shoreline.

4. Groundwater recharge by rainfall or irrigation will also affect leachate movement.

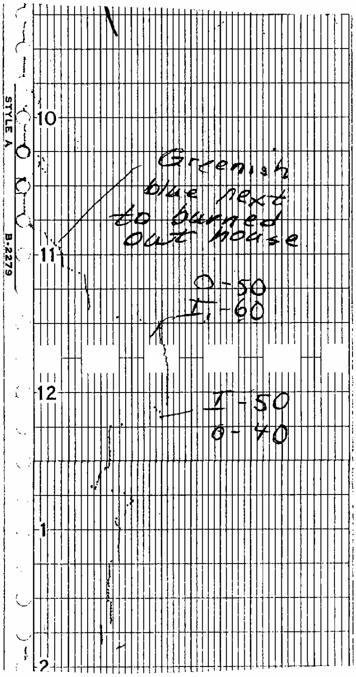
5. Naturally fluorescent decay products from dead vegetation that fluoresce in the detection range of the fluorometer.

6. Groundwater inputs or stirred up organic sediments may give false positive responses.

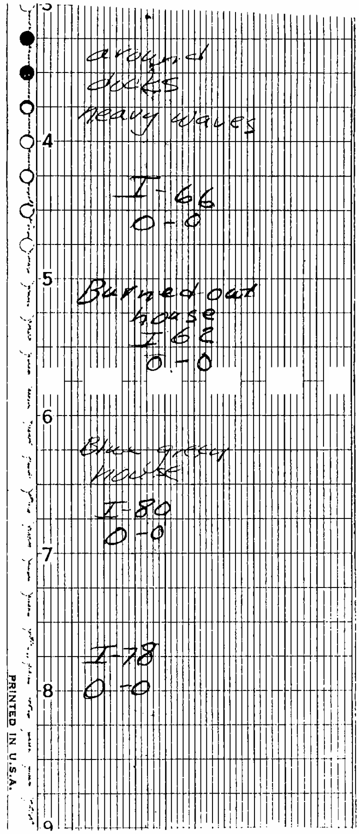
A number of possible explanations for the results of this survey are discussed below. Conditions described above may have played an important role.

1. The positive SLD responses, most of which were largely, inorganic in origin, may have been caused by groundwater inputs unrelated to septic tank leachate plumes.

   Although the groundwater gradient in the Cedar Lake area is quite shallow and generally slopes away from the western and southern shores of the lake (Figure 2-2), groundwater flow into and out of Cedar Lake can vary seasonally (see Chapter 3). However, groundwater flow during the summer months is primarily out of the lake, as indicated by falling lake levels and lack of surface outflow. It is

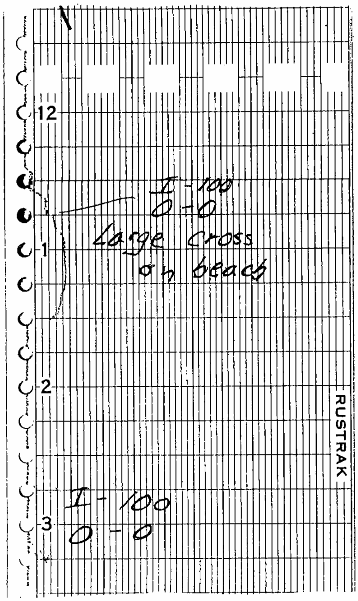


July 6, 1982

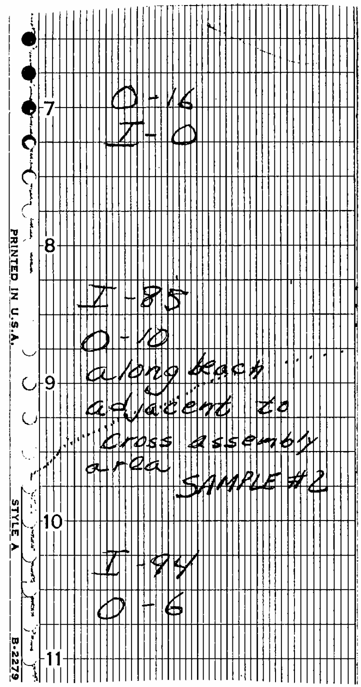


July 7, 1982

Figure 2-47. Example of SLD strip chart from the same lakeshore area on successive days. Note that the positive response on July 6 was not repeated on July 7. Heavier waves on July 7 (see chart note) may have dispersed an existing plume.

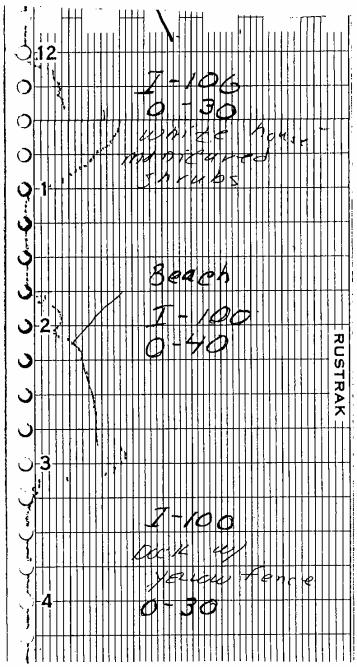


July 6, 1982

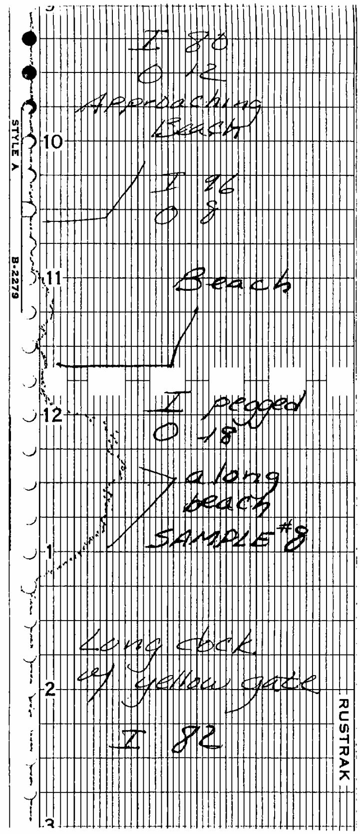


July 7, 1982

Figure 2-48. SLD strip chart from Sample Site #2 on successive days.

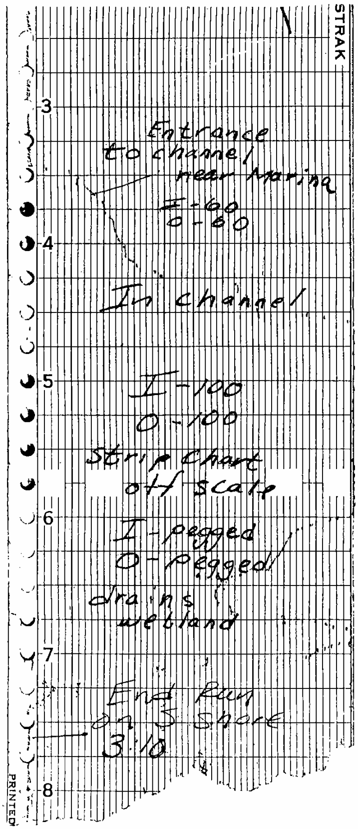


July 6, 1982

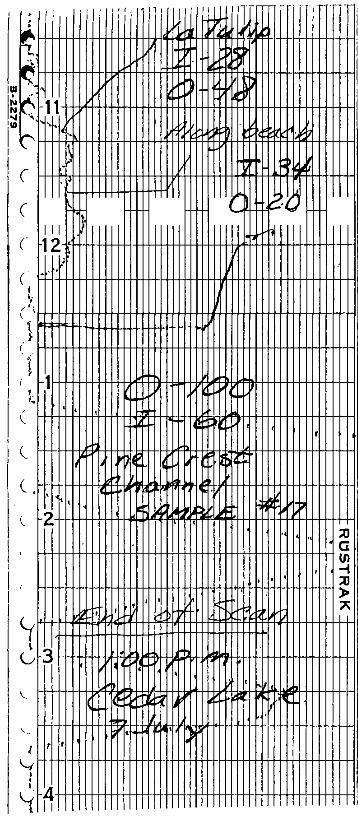


July 7, 1982

Figure 2-49. SLD strip chart from Sample Site #8 on successive days.



July 6, 1982



July 7, 1982

Figure 2-50. SLD strip chart from Sample Site #17 on successive days.

possible that heavy rains, which occurred in the week preceeding the survey, may have recharged the water table enough to allow for groundwater inflow to the lake. No groundwater elevation or flow measurements were be made to confirm this.

2. The concentration of phosphorus inputs into the lake through groundwater or septic leachate, if it occurs at all, are similar to in-lake concentrations of phosphorus.

   Ellis and Childs (1973) report phosphorus movements up to 115 feet downgradient from septic tank drain fields in loamy sand soils around Houghton Lake. Phosphate (PO_4-P) concentrations at this distance were as high as 5830 ug/l. In more loamy soils around Gull Lake, Ellis (in Jones and Lee 1977) found maximum phosphorus movement of only 30 feet. Ellis stated that until the soils become saturated with phosphorus, nearly 98 percent of the phosphorus entering the ground would be adsorbed by soils. Childs (in Jones and Lee 1977) concluded that the adsorptive capacity of soil may be as great under water-saturated conditions and under aerated conditions.

   Septic disposal sites which yield significant concentrations of phosphorus in adjacent groundwaters are generally characterized by one or more of the following: high water table, heavy system loading, old systems, and coarse sand soil (Dudley and Stephenson 1973). The first three of these conditions occurred at Cedar Lake prior to 1977. Soils around Cedar Lake have a high clay content which gives them a greater adsorptive capacity for phosphorus than sandy soils.

   Inactive systems, which predominate around Cedar Lake are not expected to contribute appreciable amounts of phosphorus to the lake after several years of non-use (J.G. Shilling and G.D. Cooke, pers. comm.). The remaining concentration of active systems at the Cedar Lake Bible Conference Center may be effectively removing phosphorus. This is a relatively new system with a sand filtration bed, however it receives heavy seasonal loadings.

3. Wave action may have dispersed any existing plumes sufficiently enough to hamper accurate analysis.

   Winds on Cedar Lake gradually increased on the day of water sampling (July 7) from calm to approximately 10 MPH. Plumes identified and sampled were done so during calm periods or on the leeward side of the lake. Wave action from motor boat activity became more noticeable after 11:00 AM while scanning the southern shore of the lake (leeward). Waves can interfere with the operation of the SLD by dispersing wastewater plumes and making them difficult to detect. More research must be done to determine the optimum operating range of the SLD in windy conditions.

2.9.5 Conclusions

Because septic leachate detection with a SLD is a new technology, care must be taken in interpreting any results. During the two-day survey on Cedar Lake, many positive responses were recorded. Few of these possible plumes contained phosphorus or coliform bacteria levels above background lake levels. Leaching from on-site septic systems was not apparent during this period. Additional scans using the SLD might help to confirm this finding.

2.10 COMPARISON OF THE EXISTING ENVIRONMENT TO THE PAST ENVIRONMENT

The historical water quality record for Cedar Lake is quite variable. Partial records exist for November 1963, July 1975, August 1976, September 1977, and May 1978 to September 1978 (Indiana State Board of Health 1975-78). Unfortunately, not all sites nor all parameters were measured for each date. In addition, the analytical methods used to perform the tests are not described. These factors make comparisons to current data difficult. However, some inferences can be drawn from this record.

Values for most of the historical water quality parameters compare favorably with our 1979 data. Historical nitrate data are not available for the early spring when we recorded the highest concentrations of this nutrient. Summer nitrate values are quite similar. Total phosphorus measurements taken from six locations during November 1963, averaged over 700 ug/l. Highest values for 1976 to the present have never exceeded 400 ug/l. Whether this reflects an overall decrease in phosphorus concentrations in the lake cannot be adequately assessed.

Values for the streams feeding Cedar Lake are even more difficult to compare due to uncertainties in flow conditions. Stream F (Sleepy Hollow Ditch), which received wastewater effluent from the Utilities Inc. (Utopia) wastewater treatment plant, had a total phosphorus concentration of 1200 ug/l for July 10, 1975. The wastewater treatment plant was still discharging effluent into the stream at that time. The wastewater treatment plant's average discharge of 100,000 gallons per day was probably sufficient to maintain some flow in the stream throughout the year. Average concentrations of other pollutants in the effluent from this plant were 51 mg/l BOD_5, 33 mg/l suspended solids, 19 mg/l ammonia (NH_3-N) and 9.8 mg/l phosphorus (PO_4-P) (Northwestern Indiana Regional Planning Commission 1978). These values represent an appreciable loading to Cedar Lake.

Perhaps a more effective means to compare historical and current lake conditions is fecal coliform bacteria counts. From April to October 1975, the Lake County Health Department (1979) collected 24 sets of samples at 10 locations in the lake. Some of the higher values, in units of colonies/100 ml, include: Site 3 - mean 290, high 2320, 5 values between 500-800; Site 10 - mean 5965, high 30,000, median 3,000 (Figure 2-22). The seasonal mean at all three of these sites exceed the Indiana state standards for full-body contact (200/100 ml).

Table 2-27 compares the frequency that the state standards were exceeded for 1975 and 1979. From this table, it can be seen that the frequency of wastewater discharging into Cedar Lake, as indicated by coliform bacteria, has significantly decreased since the completion of the sanitary wastewater treatment system in 1977.

Table 2-27. Percentage of dates that Cedar Lake exceeded Indiana's fecal coliform standards for full-body contact. (--) indicates that the site was not sampled.

Site	1975	1979
1	29	0
2	21	11
3	33	17
4	4	6
5	4	6
6	17	6
7	13	0
8	--	6
9	8	0
10	29	17
Sleepy Hollow Ditch	96	--

CHAPTER 3: WATER BUDGET

3.0 OVERVIEW

Water budgets for Cedar Lake were derived from the following mass balance equation:

$$\Delta V = (P-E) + R + G - S_o$$

ΔV = change in storage
$(P-E)$ = net precipitation (precipitation - evaporation) to the lake surface
R = total basin runoff (stream inflow + sheet runoff)
G = groundwater inflow
S_o = surface outflow (to Cedar Creek)

All components are expressed in units of $10^6 m^3$.

Since all budget components are at least partially dependent upon precipitation, budgets were calculated for three water years: 1971-72, a wet year; 1974-75, a typical year relative to precipitation; and 1977-78, a dry year. Furthermore, to detect seasonal trends, separate budgets were calculated within each year for the periods of November to February, March to June, and July to October. The significance of these periods will become apparent during consideration of nutrient budgets for Cedar Lake.

Water budgets for Cedar Lake during the three years previously mentioned are summarized in Table 3-1. Component derivation is discussed in the following section. Total precipitation, as measured at Lowell, Indiana, from January through August, 1979 was .4 inches above the normal used in calculating the water budget for a typical year (National Oceanic and Atmospheric Administration 1979). For this reason, the typical year water budget (1974-75) is probably the best estimate for a 1979 water budget.

3.1 DETERMINATION OF COMPONENT CONTRIBUTIONS

3.1.1 Change in Storage

Change in storage (ΔV) was calculated from stage records (U.S. Geological Survey files) at a gaging station next to the dam at the outlet of Cedar Creek. It was assumed that the lake's surface area does not vary significantly with changes in level. Change in storage for November-February was multiplied by 0.95 to correct for ice cover, which was measured as 0.5 m thick in February, 1979.

3.1.2 Net Precipitation

Net precipitation (P-E) was calculated from National Oceanic and Atmospheric Administration (NOAA) data (1971-1978). Precipitation measurements are from the Lowell Wastewater Treatment Plant and pan

Table 3-1. Water Budgets for Cedar Lake where $\Delta V = (P - E) + R + R - So$. Units expressed as $10^6 m^3$. (-) indicates a net loss.

YEAR	COMPONENT	NOV-FEB	MAR-JUNE	JULY-OCT	ANNUAL
	Net Precipitation	0.39	0.74	1.21	2.34
	Runoff (R)	0.88	1.93	2.41	5.22
1971-72	Surface Outflow (So)	-0.55	-3.27	-2.59	-6.41
("wet")	Groundwater (G)	-0.37	0.68	-0.89	-0.58
	Storage (ΔV)	0.35	0.08	0.14	0.57
	P-E	0.65	0.76	0.14	1.55
	R	1.22	1.79	1.23	4.24
1974-75	So	-2.39	-3.67	-0.36	-6.42
("typical")	G	1.03	1.10	-1.54	0.59
	ΔV	0.51	-0.02	-0.53	-0.04
	P-E	0.27	0.22	0.17	0.66
	R	0.70	1.46	1.03	3.19
1977-78	So	-1.27	-2.49	0.00	-3.76
("dry")	G	0.63	0.61	-1.81	-0.57
	ΔV	0.33	-0.20	-0.61	-0.48

evaporation measurements are from the Valparaiso Water Works. A standard pan coefficient of 0.7 was assumed and missing evaporation data were estimated according to Chow (1964) or by interpolation. These data were converted to meters and multiplied by the surface area of Cedar Lake ($3.16 \times 10^6 m^2$), yielding (P-E) in $10^6 m^3$.

3.1.3 Total Basin Runoff

Total basin runoff (R) was estimated as follows. An annual runoff coefficient of 0.20 was determined according to Chow (1964) by using hydrologic soil groups and runoff curve numbers for hydrologic soil-cover complexes to calculate the runoff coefficient. The coefficient value of 0.20 compared favorably to water yields from gaged basins of similar size and land use characteristics. This value was also confirmed by runoff data presented by the Governor's Water Resources Study Commission Phase I report for Indiana (1978). Basin runoff (R) was then calculated seasonally according to the formula:

$$R = cPA$$

where: c = runoff coefficient = 0.20
P = precipitation, m
A = basin area = $18.42 \times 10^6 m^2$

The calculated runoff values include stream inflow and overland (sheet) flow.

3.1.4 Surface Outflow

Surface outflow (So) was calculated from daily USGS stage data and a rating curve developed during this study from 25 stream gaging surveys undertaken by U.S. Geological Survey personnel over the last 20 years. November to February discharges were multiplied by 0.9 to correct for possible ice accumulations on the crest of the dam separating Cedar Lake from Cedar Creek.

3.1.5 Groundwater

Groundwater (G) was determined as a residual. Estimates for other components were used to solve the mass balance equation for groundwater flow. This approach is recommended by Cooke at al. (1978) because groundwater is by far the most difficult budget component to measure or empirically derive.

3.2 DISCUSSION

The data in Table 3-1 illustrate the influence of annual and seasonal climatic shifts on the hydrology of Cedar Lake. This is particularly true for groundwater, which can assume greater importance seasonally even when relatively insignificant on an annual basis. A simplistic mechanism for this seasonal variation is suggested, in part, by the rather unique hydrological position of Cedar Lake.

During the period of spring runoff, groundwater is recharged thus raising the water table while at the same time, surface stream flows are at their maximum. Both groundwater and surface flow contribute to Cedar Lake at this time resulting in surface outflow over the lake level control dam at the outlet to Cedar Creek. Because of the small drainage area, surface inflow soon ceases and outflow also ceases once the lake level falls below the dam's spillway elevation of 693 feet Mean Sea Level (M.S.L.).

The elevation of the groundwater table near the shoreline of Cedar Lake begins dropping early summer due to a combination of the following: 1) lack of a large recharge area, 2) limited lateral flow, 3) the hydraulic gradient drops away from Cedar Lake on three sides, and 4) consumptive use by private wells surrounding the lake. As this occurs, the potentiometric surface of the groundwater drops below that of the lake since the lake's level is artificially maintained by the control structure. This potential difference causes the lake water to recharge the groundwater by seepage through the lake bottom. Lake elevation continues to drop in this way until fall rains recharge the groundwater and surface flow into the lake resumes.

In a very dry year such as 1976-77, gaging station records show that the lake elevation continued to drop in this manner from March, 1976 until the following winter, a total of nearly 1.5 feet. During 1979, the gage height dropped from 3.47 on May 3 to 2.63 on July 10. This represents a lake elevation drop of 0.84 feet. Since precipitation exceeds evaporation (P-E), even in the summer, the lake elevation drop (Δ V in Table 3-1) must be attributable to groundwater outflow.

The most noteworthy hydrologic feature of Cedar Lake relevant to this study is its lack of surface outflow during long periods of the year. In 1978, Cedar Creek did not flow from early June through December, though more typically outflow is very low only from July to October. This suggests that Cedar Lake may have a long hydraulic residence time.

The hydraulic residence time is defined as the ratio of the water body volume to the annual water inflow volume and represents the time necessary to exchange the total volume of water within a lake. Hydraulic residence time is calculated from the following equation (Rast and Lee 1978):

$$T_W = \frac{V}{Q}$$

where: V = lake volume (m^3)
Q = annual water inflow rate (m^3/yr)

When applied to the three estimated water budgets for Cedar Lake, the following residence times are obtained:

1971-72 (wet)	$Tw = \frac{V}{Q} = \frac{8.44 \times 10^6 m^3/yr}{7.56 \times 10^6 m^3}$	= 1.12 years
1974=75 (typical)	$Tw = \frac{V}{Q} = \frac{8.44 \times 10^6 m^3/yr}{6.38 \times 10^6 m^3}$	= 1.32 years
1977-78 (dry)	$Tw = \frac{V}{Q} \quad \frac{8.44 \times 10^6 m^3/yr}{3.85 \times 10^6 m^3}$	= 2.19 years

The optimum hydraulic residence time for a lake is a complex function of the rate, duration, and pattern of flow through the lake and the time of the year during which flow occurs. The rate of flow, otherwise referred to as the flushing rate (ρ), is simply the inverse of the hydraulic residence time (Tw) (Uttormark and Hutchins 1978), or:

$$\rho = \frac{Q}{V}$$

For Cedar Lake, calculated flushing rates range from 0.90 lake volumes/year for wet years, 0.76 volumes/year for typical years and 0.46 volumes/year for dry years. Flow through Cedar Lake does not occur throughout the entire year but rather, during the spring and fall seasons when lake elevations are high and nutrient concentrations are lowest. Because of the locations of the three inlet streams and the outlet, the pattern of flow is largely restricted to the southern one-half of the lake.

Similar short circuiting of incoming flow has been documented for Silver Lake, New York by Englert and Stewart (1983). Short-circuiting can reduce the effective flushing rate, as it relates to nutrient removal, below that calculated by Uttormark and Hutchin's model, since the model assumes that the entire water mass is mixed in the process. The incomplete mixing and seasonal discharge can lead to overestimation of the rate of nutrient flushing from Cedar Lake.

CHAPTER 4: NUTRIENT BUDGET

4.0 OVERVIEW

As discussed in Section 2.7, the data collected and analyzed in 1979 indicate that Cedar Lake is nitrogen limited at times. This is due primarily to the excessive phosphorus levels in the lake. Phosphorus is generally believed to be the aquatic plant nutrient most frequently controlling eutrophication in natural waters (Vollenweider 1968). Much of the phosphorus supplied to water bodies is introduced by way of point sources although non-point (diffuse) sources also contribute. Nitrogen, however, is often introduced in large quantities from more diffuse sources than phosphorus. These diffuse sources include the fixation of atmospheric nitrogen by aquatic plants. Consequently, it is believed that the control of phosphorus loading to a water body is technically and economically more feasible than control of nitrogen loading (Rast and Lee 1978). For these reasons, nutrient budgets have been prepared for phosphorus only.

4.1 BUDGETING APPROACH

Based largely on Vollenweider's (1968; 1975) work, Simpson and Reckow (1979) have developed a simple empirical phosphorus model for the prediction of lake phosphorus concentration associated with land uses in the watershed. The model was developed from 47 north temperate lakes included in the U.S. Environmental Protection Agency's National Eutrophication Survey. The model expresses phosphorus concentration (P, in mg/l) in the form:

$$P = \frac{L}{v_s + q_s} \qquad (1)$$

Where: L = total phosphorus loading ($g/m^2/yr$)

v_s = apparent phosphorus settling velocity (m/yr)

q_s = areal water loading (m/yr)

Simpson and Reckow (1979) found that apparent settling velocity was a weak function of q_s. Thus the model becomes:

$$P = \frac{L}{11.6 + 1.2\, q_s} \qquad (2)$$

A few limitations of the model should be discussed here:

1. The model should only be used for lakes within the north temperate climatic zone.

2. The model should only be applied to lakes with variable values which fall within the ranges reported for the 47 study lakes - P (0.004 mg/l to 0.135 mg/l), L (0.07 $g/m^2/yr$ to 31.4 $g/m^2/yr$), and q_s (1.23 m/yr to 187 m/yr).

3. In the 47 study lakes, internal loading of phosphorus from the lake sediments was unimportant. Therefore, the model does not accurately account for internal loading in lakes where internal loading is sizable.

The model limitations, as described, do not pose major problems in applying Simpson and Reckow's model to Cedar Lake. Although the measured average total phosphorus concentration for Cedar Lake (0.172 ug/l) exceeds the range for the model lakes, the phosphorus concentration, as predicted by the model, resulting from external loading of phosphorus falls within the range. It is this predicted concentration that is used to estimate internal loading.

Measured phosphorus levels for Cedar Lake suggest that internal loading is considerable. Since the model predicts the phosphorus concentration expected in Cedar Lake under conditions of no internal loading, solving the equation for L allows calculation of total external loading (L_E) in terms of P. By using measured values of P and solving for L, total loading (L_T) from both external and internal sources can be estimated. L_T - L_E will then yield a good first approximation for total internal loading. Thus:

$$L_I = L_T - L_E \qquad (3)$$

4.2 CALCULATION OF AREAL WATER LOADING (q_s)

Areal water loading (q_s) to Cedar Lake is calculated as:

$$q_s = \frac{Q}{A} = \frac{(\ (P-E) + R\ )}{A}$$

where: Q = total inflow (m^3)
P = precipitation (m^3)
E = evaporation (m^3)
R = total basin runoff (m^3)
A = lake surface area (m^2)

From the estimated 1974-75 water budget for a typical water year (see Chapter 3) the expression becomes:

$$q_s = \frac{5.8 \times 10^6 m^3}{3.16 \times 10^6 m^2} = 1.84 \text{ m}$$

4.3 DETERMINATION OF COMPONENT CONTRIBUTIONS

Since the phosphorus model is a simplification, high, low, and mid-range or "most likely" estimates of external loading were calculated. Table 4-1 identifies general non-point phosphorus source categories along with a range of phosphorus export coefficients as suggested by Simpson and Reckhow (1979). An export coefficient represents the expected annual amount of phosphorus transported, per unit of source, to a surface water body. The values are representative of those found in the literature. Simpson and Reckhow (1979) have subjectively classified the coefficients into high, low, and mid-range estimates.

Table 4-1. Phosphorus export coefficients (units are kg/$10^6 m^2$, except for septic tank).*

Estimate Range	Agricul-ture	Forest	Precipi-tation	Urban	Urban Storm Sewer	Septic Tanks (kg./capita/yr)
High	200	80	60	200	800	1.8
Mid	20-50	10-50	20-50	70-120	300-600	0.4-0.9
Low	10	15	50	50	100	0.3

*From Simpson and Reckhow (1979).

Because of the wide degree of variation among watersheds with regard to basin geology, erosional pattens, and intensity and types of use, each value used in the model must be "custom" selected by the modeler for a particular lake. The values that were selected for use with Cedar Lake under high, low, and mid-range estimates are given in Table 4-2.

For all estimates, phosphorus loading from wetlands was assumed to be the same as loading from agricultural lands. Agricultural lands were generally given low loading values due to their location away from the lake and the lack of drainage from these lands via stream flow during the growing season.

Septic tank loading values tend toward the average of the suggested literature values. Although the high water table, poor drainage, inadequate setbacks, and inadequate lot sizes surrounding Cedar Lake all suggest the probable failure of septic tank systems, active use of septic systems at Cedar Lake currently occurs only at the Conference Grounds where a large sand filtration bed jointly serves approximately 80 year round residences (C. Walker, Town of Cedar Lake Clerk-Treasurer, pers. comm.). This system is new and presumed to be functioning properly (see Section 2.9).

Inactive septic tank systems were assumed to be contributing negligible amounts, if any, of nutrients to Cedar Lake after several years of non-use. Although little research has been conducted regarding leaching from inactive drain fields, current research by J.G. Schilling, Coordinator of Minnesota's Clean Lakes Grant Program (pers. comm.) and G.D. Cooke, Professor of Biological Sciences at Kent State University (pers. comm), suggest that after several years and under normal circumstances, most of the available nutrients within drain fields are leached or precipitated. The results of the septic leachate detection survey (Section 2.9) confirmed this for Cedar Lake.

Table 4-2. High, mid-range, and low estimates of external loading for Cedar Lake.

Source	Areal Loading ($kg/10^6m^2$)	Area (10^6m^2)		Mass Loading (M) (kg/yr)
		HIGH		
Forest	40	0.66		26.4
Wetland	40	1.69		67.6
Ag/open	80	11.55		924.0
Urban	150	4.50		675.0
Septic	1.8(kg/cap/yr)	248 people*		446.4
Precip	57	3.16		180.0
			TOTAL	2319.4
		MID-RANGE		
Forest	15	0.66		9.9
Wetland	15	1.69		25.4
Ag/open	30	11.55		246.5
Urban	90	4.50		405.0
Septic	0.65(kg/cap/yr)	248 people*		161.2
Precip.	57	3.16		180.0
			TOTAL	1028.0
		LOW		
Forest	2	0.66		1.3
Wetland	2	1.69		3.4
Ag/open	10	11.55		115.5
Urban	50	4.50		225.0
Septic	0.3(kg/cap/yr)	248 people*		74.0
Precip.	57	3.16		190.0
			TOTAL	609.6

*80 residences x 3.1 persons/residence (C. Walker pers. comm.)

Values for precipitation loading to Cedar Lake were derived from field measurements and confirmed by literature values (see Section 2.4).

The major source categories of external mass loading of phosphorus to Cedar Lake in all three estimates are agricultural/open, urban, and septic tanks. Precipitation becomes more important under the low estimate. For comparison, an estimate of external loading to Cedar Lake prior to the construction of the wastewater collection system is presented in Table 4-3, using the "most likely," or middle range estimates for external areal loading. This estimate includes the former septic system source of loading and the additional loading from the former Utopia wastewater treatment plant (WTP) effluent (Northwestern Indiana Regional Planning Commission 1977).

Table 4-3. Estimate of external loading to Cedar Lake prior to the wastewater collection system.

Source	Areal Loading ($kg/10^6m^2$)	Area (10^6m^2)	Mass Loading (M) (kg/yr)
Forest	15	0.66	9.9
Wetland	15	1.69	25.4
Ag./open	30	11.55	346.5
Urban	90	4.50	405.0
Septic	1.0(kg cap/yr)	1240 people*	1240.0
Precip.	57	3.16	190.0
Utopia WTP	--	--	1357.6
		TOTAL	3574.4

*400 residences with 100 m of shore x 3.1 persons/residence.

Under the "most likely" conditions prior to the installation and operation of the wastewater collection system, total external loading to Cedar Lake was quite significant. In this estimate, the septic system loading represented 35% of the total, and the Utopia wastewater treatment plant loading represented 38% of the total external loading. These two sources alone are estimated to have contributed more than twice the loading from all present day sources under the "most likely" estimate in Table 4-2.

4.4 CALCULATION OF ANNUAL AREAL PHOSPHORUS LOADING (L)

In order to be used in the model, external phosphorus loading must be expressed in grams per square meter of lake surface area per year. Thus mass loading (M) must be converted to areal loading using the equation:

$$L_E(g/m^2/yr) = \frac{M(kg/yr) \times 1000}{A\ (10^6m^2)}$$

For Cedar Lake:

high

$$L_E \text{ (high)} = \frac{2319.4 \text{ (kg/yr)} \times 1000}{3.16\ (10^6 m^2)} = 0.73 \text{ g/m}^2\text{/yr}$$

middle

$$L_E \text{ (middle)} = \frac{1028.0 \text{ (kg/yr)} \times 1000}{3.16\ (10^6 m^2)} = 0.33 \text{ g/m}^2\text{/yr}$$

low

$$L_E \text{ (low)} = \frac{609.6 \text{ (kg/yr)} \times 1000}{3.16\ (10^6 m^2)} = 0.19 \text{ g/m}^2\text{/yr}$$

4.5 CALCULATION OF LAKE PHOSPHORUS CONCENTRATION (P)

The model can now be solved for high, middle, and low phosphorus concentration from Equation 2:

$$P = \frac{L}{11.6 + 1.2\ qs} = \frac{L}{13.81}$$

For Cedar Lake:

high

$$P \text{ (high)} = \frac{0.73}{13.81} = 0.053 \text{ mg/l}$$

middle

$$P \text{ (middle)} = \frac{0.33}{13.81} = 0.024 \text{ mg/l}$$

low

$$P \text{ (low)} = \frac{0.19}{13.81} = 0.014 \text{ mg/l}$$

These values represent the expected high, middle, and low phosphorus concentrations for Cedar Lake in typical water years such as 1974 or 1979.

4.6 CALCULATION OF INTERNAL LOADING (L_I)

As stated previously, internal loading within Cedar Lake can be calculated by comparing external loading (L_E) as predicted by the model and total loading (L_T) as determined from measured lake water phosphorus levels by the following relationship:

$$L_I = L_T - L_E$$

Lake phosphorus concentrations averaged 0.220 mg/l from April to September of 1979. A concentration of 0.130 mg/l was determined from a sample taken on March 2, the only one during ice cover. By assuming that this concentration accurately represents phosphorus concentrations for October to April (probably an under-estimation), than an average yearly phosphorus concentration of 0.172 mg/l can be calculated. Substituting this value for P in Equation 2 and solving for L, yields L_T:

$$L_T = P\ (13.81) = 2.38\ g/m^2/yr \text{ for a typical water year}$$

Solving for L_I now gives us:

<u>high</u>

$$L_I = 2.38\ g/m^2/yr - 0.73\ g/m^2/yr = 1.65\ g/m^2/yr\ (69\%)$$

<u>middle</u>

$$L_I = 2.38\ g/m^2/yr - 0.33\ g/m^2/yr = 2.05\ g/m^2/yr\ (86\%)$$

<u>low</u>

$$L_I = 2.38\ g/m^2/yr - 0.19\ g/m^2/yr = 2.19\ g/m^2/yr\ (92\%)$$

In all three estimates internal loading, as calculated, represents a significant percentage of the total phosphorus loading to Cedar Lake.

4.7 SEDIMENT RELEASE MECHANISMS

The ability of sediments to adsorb nutrients is well documented (see for example, Shukla et al. 1970), however the significance of lake sediments as an internal source of lake fertilization is still poorly understood. The uptake and release of nutrients by sediments is a complicated function of interacting physical, chemical, and biological processes. The interrelationships among these processes makes them difficult, if not impossible, to evaluate separately.

4.7.1 Chemical Exchange

Chemical exchange of phosphorus across the sediment interface is regulated by mechanisms associated with mineral-water equilibria, sorption processes (notably ion exchange), and redox potential. The most conspicuous regulatory feature of the sediment boundary is the mud-water interface and the oxygen content at this interface (Wetzel 1975). An oxidized microzone is a critical factor in regulating exchange between sediments and water. It serves as an effective barrier to the release of soluble components, particularly phosphorus.

The cycling of phosphorus is closely related to iron forms and their availability (Theis and McCabe 1978). As oxygen is depleted in the water near the sediment-water interface, the barrier of the oxidized microzone is decreased, iron is reduced, and the solubility of phosphorus is increased. Work by Stevens and Gibson (1977) has demonstrated that phosphorus can be released in this way while the dissolved oxygen concentration in the water just above the sediment was as high as 50% saturation. If anoxic water existed above Cedar Lake sediments, it must have occupied a layer, possibly only a few centimeters deep, which could not have been located accurately by an oxygen probe.

During quiescent periods, the exchange of nutrients between the sediments and overlying water has been reported to be governed by a concentration dependent diffusion (Weiler 1973). Release of nutrients from sediments to the interstitial water is controlled by an equilibrium reaction between the concentration of nutrients already in the interstitial water and the particle concentration. Once an equilibrium has been established, additional release of particle nutrients becomes dependent on the rate of diffusion from the intersititial water into the overlying water column. Diffusion rates can be quite slow, however physical mixing of the sediments causes on accelerated release of particle nutrients by mixing interstitial waters more rapidly with the overlying water column.

In Cedar Lake, the average percent dissolved oxygen saturation just above the sediments decreased from 95% to 35% saturation from May 11 to July 20, 1979. At the same time, average total phosphorus concentrations increased from 95 ug/l to 325 ug/l. These events suggest the possibility of chemical release of phosphorus from the sediments, given the lack of surface water inputs.

It should be noted that dissolved oxygen measurements were taken during the day from near the lake bottom. Saturation values at the sediment-water interface during the nightime hours are probably lower, as suggested by the results of the 24-hour analysis (Section 2.2.9).

4.7.2 Wind

A study of several Swedish lakes by Ryding and Forsberg (1977) found that water quality and the force and duration of the lengthwise winds in a lake were correlated, indicating that mixing plays a dominant role in the transport of nutrients from the sediments in shallow lakes. Increases in ammonia and total phosphorus were observed when the wind was blowing lengthwise along the lakes. In fact, phosphorus release rates can nearly double when sediments are disturbed by agitation from turbulance (Zicker et al. 1956). Lee (1970) suggests that mixing by wave actions, currents, burrowing animals, and gas ebullition, is of much more importance for the nutrient release from sediments than is diffusion.

4.7.3 Motor Boats

Yousef et al. (1978; 1979), in a study of three shallow lakes in Florida, found that induced waves due to motorboats resuspended bottom sediments, increased turbidities, and increased phosphorus release. Sediment resuspension is controlled by the motor boat/engine combination, water depth, sediment fineness, and depth of sediment above firm soil. Based on their work, Yousef et al. were able to prepare a set of curves which show the engine horsepower required to scour sediment particles of sizes varying from 0.05 millimeter to 1.0 millimeter diameter at water depths up to 10 feet (Figure 4-1). (Cedar Lake surficial sediments range between 0.0002-0.074 millimeters in diameter). This figure can be used as a guide to determine the maximum housepower permitted on a lake with known depth and bottom sediments fineness and specific gravity. For example, according to Figure 4-1, a 60 hp motorboat could resuspend sediments in Cedar Lake to a depth of 10 feet (62% of the lake's bottom area).

Turbidity increases due to resuspension of bottom sediments may be accompanied by increases in phosphorus and chlorophyll (Yousef et al. 1978). Zicker et al. (1956) report that phosphorus release from sediments doubles due to agitation from turbulence. Sediment mixing allows the interstitial water, which can contain 50 times more phosphate (PO_4), to mix with the overlying water. Because of the equilibrium relationship, more sediment phosphorus then diffuses upward to replace the phosphorus lost to the water column. In the Florida lakes that Yousef et al. studied, the maximum increases in SRP release with boating activities were: 16% at 3.4 meters depth, 43% at 2.6 meter, and 73% at 1.5 meters. When these values are compared to the depth of Cedar Lake (maximum-4.9 meters; average-2.7 meters) it can be inferred that high speed motor boats on the lake could be causing the release of significant quantities of phosphorus from the sediments.

4.7.4 Biological Processes

Biological processes affecting the release of nutrients from sediments include bioturbation, which is the stirring of sediments by the activity of burrowing benthic organisms, and fish excretion. Gallepp (1979) has demonstrated that phosphorus cycling by chironomids can be significant, up to 45 mg/m^2/day in Lake Mendota, Wisconsin. Release by chironomids can occur under anaerobic and aerobic conditions, although anaerobic release rates are typically several times higher than aerobic rates. Bioturbation caused by other invertebrates such as oligochaete worms, insect larvae, and crustaceans are discussed in Petr (1977).

Shapiro et al. (1975) present data which show that carp (Cyprinus carpio), which feed on organic sediment material, can release significant levels of phosphorus through excretion. Release rates are inversely proportional to fish size; a 10 g carp releasing 10 ug/g/hr total phosphorus and a 100 g carp releasing 3 ug/g/hr. Table 4-4 presents carp biomass data collected during the fisheries survey on August 22, 1979. The sample biomass was used to estimate carp biomass for the whole lake by a method suggested by Bob Robertson, Indiana Department of Natural Resources (per. comm.). Shapiro et al. (1975) total phosphorus release rates for carp were then used to estimate total yearly mass loading of phosphorus to Cedar Lake from carp.

The estimated total mass of phosphorus released from Cedar Lake sediments by carp was calculated to be 982 kg/yr total phosphorus or 0.31 g/m^2/yr. When compared to the estimated internal yearly mass loading of phosphorus to Cedar Lake for the "most likely" estimate (6478 kg/yr), carp release accounts for 15%. This represents a significant amount of phosphorus release by carp.

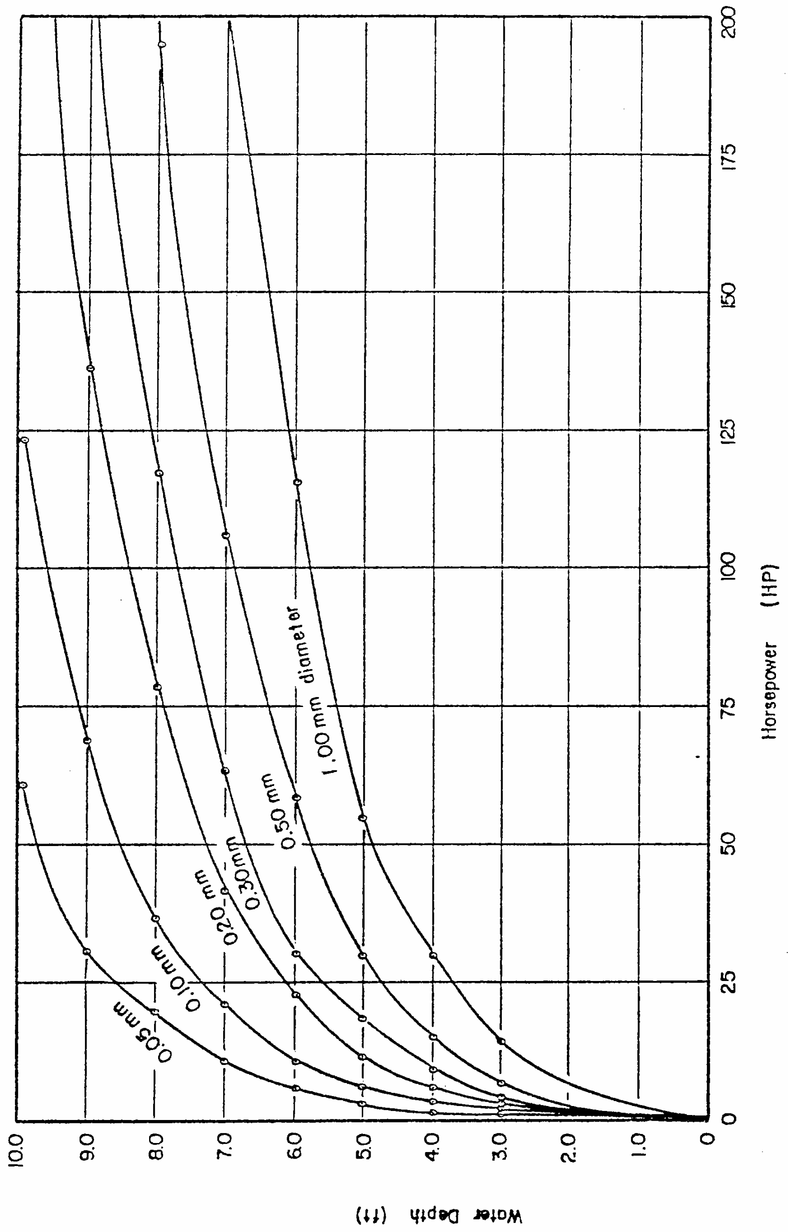


Figure 4-1. Bottom sediment resuspension by recreational motorboats in shallow lakes. From: Yousef et al. (1978).

Management programs can be effective. In Wisconsin, a turbid lake with a Secchi disk visibility of about 0.3 meters was treated with toxaphene to kill rough fish. After all the fish were killed, turbidity had decreased and Secchi disk visibility had increased to several meters (Lee 1970).

Table 4-4. Carp (Cyprinus carpio) biomass[1] and estimated phosphorus resuspension in Cedar Lake.

Carp Weight Class (g)	Total Carp Biomass in Sample (g)	% (by weight)	Estimated Carp Biomass in Lake (10^6g)[2]	P Release Rate for Carp Weight Class (mg/g/hr)[3]	Total Yearly Mass of P Released (kg)
200-300	1447	2	1.70	2.1	31.3
300-400	1483	2	1.70	1.7	25.3
400-500	7949	9	7.66	1.5	100.7
500-600	28066	31	26.39	1.35	312.1
600-700	41491	46	39.16	1.25	428.8
700-800	6723	7	5.96	1.15	60.0
800-900	2465	3	2.55	1.05	23.5
	89624	100	85.12		981.7

[1]Sampled on August 22, 1979

[2]Percent of carp by weight x 109 kg carp per acre x 781 acres.

[3]From Shapiro et al. (1975).

4.8 DISCUSSION

From a phosphorus management standpoint, the major historical inputs to Cedar Lake, septic tank drainage and the effluent from the Utopia wastewater treatment plant, have been eliminated. However, loading from these sources occurred over a number of years, allowing the build-up of phosphorus levels in the sediments. This build-up was facilitated by low surface water inflow which limited lake flushing. Today, flushing of these stored nutrients is still limited by low flow-through.

The levels of phosphorus attributable to internal loading by the model fall within the range of values determined experimentally and presented in the literature (Table 4-5). Values for Cedar Lake range from 1.65 to 2.19 g/m^2/yr, whereas literature values range from 0.4 to 27.6 g/m^2/yr. The internal loading of phosphorus, as calculated, ranged from 69 to 92% of the total loading. This compares favorably to values of 65 to 105% from Twin Lakes, Ohio as reported by (Cooke et al. 1977). Given this, our estimate of internal phosphorus loading to Cedar Lake seem reasonable. However, it is not possible to apportion release loadings among all of the various mechanisms involved.

Table 4-5. Comparison of phosphorus release from sediments.

Release rate ($g/m^2/yr$)	Temp (°C)	Sediment Source	Citation
Aerobic sediments			
0.4	24-30	Lake Warner (Mass.)	Fillos and Swanson (1975
2.9-3.3	20	Lake Esrom (Denmark)	Kamp-Nielson(1975)
1.3	15	Gnadesee (Germany)	Banoub (1975)
3.4	25	" "	
0.4-1.1	20	Narragensett Bay (Rode Island)	Hale (1975)
0.4-1.8		Lake Mendota (Wisconsin)	Holdren (1974)
18.6		Lake Mendota, with chironomids emerging	Gallipp (1979)
Anaerobic sediments			
1.6-5.1	15	Lake Trummen (Sweden) before restoration	Bengtsson et al. (1975)
9.5 (max)	24-30	Lake Warner (Mass.)	Fillos and Swanson (1975)
13.1	8	Lake Sodra Bergundasjon (Sweden)	Bengtsson (1975)
4.1-27.6	21	Lake Charles (Indiana)	Theis et al. (1979)
1.8-26.6	9	Stone Lake (Michigan)	Theis and McCabe (1978)
Zooplankton			
2.6	summer	Lake 227 (Manitoba)	Peters (1975)
1.0	summer	Lake 302 (Manitoba)	" "
Fish (carp)			
0.4-0.8	22	Union Lake and Kuska Pond (Minn)	Lamarra (1975)

If a great deal of the phosphorus released from the sediments is recycled back to the ecosystem each season through resuspension, as is the case in Cedar Lake, then a lowered phosphorus input to the lake from external sources will have no significant effect on water quality, at least in the short run. If water quality improvements are to be realized, phosphorus release from the sediments must be limited.

CHAPTER 5: RESTORATION TECHNIQUES REVIEW

5.0 INTRODUCTION

Lake restoration techniques can be divided into two general categories: (1) those that limit fertility or control sedimentation, and (2) those that temporarily manage the consequences of eutrophication. Controlling the influx of nutrients and sediments is usually difficult and expensive but can permanently affect the underlying causes of lake problems. Other restoration methods that treat the products of overfertilization only have short-term effects. Some methods do not clearly fall into either category. For example, biotic harvesting affects both nutrient concentrations within a lake, and also manages a species population (i.e. a consequence).

The Environmental Protection Agency's "Clean Lakes Program" (Sections 314 and 104 of the Federal Water Pollution Control Act, P.L. 92-500) usually supports restorative actions that provide for long-term solutions. This may include restricting the input of undesirable materials and/or providing in-lake treatment for the removal or inactivation of undesirable material. The influx of some nutrients is necessary to maintain the fertility of lake systems because recycling of nutrients within the system is never perfectly efficient. Thus, if losses of nutrients to outflow or sediments are not compensated for by additional inputs, the fertility of the system will be reduced.

Hydraulic residence time is defined as the time required for the entire volume of water in a lake to be replaced, and is an important consideration in assessing possible restorative methods. In lakes with short hydraulic residence times the reduction (or elimination) of nutrient sources may be the only restorative measure required to achieve a desired level of improvement. However, in cases of long hydraulic residence times, the reduction of nutrient sources must usually be augmented with in-lake methods to speed up the process of water quality improvement.

Most lake restoration methods that limit fertility in a lake, focus on phosphorus and nitrogen because either one can be a limiting factor in the nutritional requirements of aquatic organisms. A nutrient that is scarce relative to other necessary nutrients can limit the biological productivity of a lake system. Changes in the quantity of a limiting nutrient will tend to directly affect productivity. Current nutrient removal technologies are often directed at phosphorus for three reasons (Sargent 1976). First, the nitrogen : phosphorus ratio necessary for sustained plant growth is about 7N:1P (Wetzel 1975). Given an adequate supply of energy and macronutrients, phosphorus is more likely to become limiting. In addition, phosphorus does not have major reservoirs in the atmosphere. Deficiencies in nitrogen can be offset by utilization of atmospheric sources. Secondly, many studies indicate that cultural activities are the major source of total phosphorus loading to a lake and thus may be easier to control; nitrogen loading is often not related to human activities. Thirdly, it is technolgically easier and more cost effective to remove phosphorus from waters than nitrogen.

The availability of phosphorus and nitrogen to lake biota is affected by the chemical form, timing and location. Orthophosphate (PO_4) is the form of phosphorus most readily used by plants. Ammonium (NH_4) and nitrate (NO_3) nitrogen are used by most algal species; some blue-green algae can use ammonia (NH_3) and nitrite (NO_2) nitrogen. Seasonal variations of nutrient inputs and the quantity of nutrients in the photic zone also affects nutrient availability to plants. Dunst et al. (1974) states that minimizing the fertility of a lake entails restricting nutrient quantities that reach the photic zone of a lake in a biologically available form at a time when they can cause undesirable growth of plants.

Dunst et al (1974) provide a comprehensive outline of lake rehabilitation technologies (Table 5-1) that will be generally followed here. Many techniques are in the experimental stage and success on individual lakes may or may not be applicable in different circumstances. Each lake ecosystem is unique (and complex) and currently there is limited capability in predicting the response of a particular lake system to various treatments.

Table 5-1. Lake restoration technologies.

I. Limiting Fertility and Controlling Sedimentation

A. Controlling nutrient inputs

1. Land use practices
2. Improved waste treatment
3. Treatment of inflow
4. Diversion
5. Product modification

B. In-lake methods to accelerate nutrient outflow or prevent recycling

1. Dredging for nutrient control
2. Nutrient inactivation/precipitation
3. Dilution/flushing
4. Biotic harvesting
5. Selective discharge
6. Sediment exposure and desiccation
7. Lake bottom sealing

II. Treating the Products of Overfertilization

5.1 CONTROLLING NUTRIENT INPUTS

5.1.1 Land Use Practices

There are several extensive literature reviews that relate watershed land-use patterns to non-point source phosphorus and nitrogen loading in streams (Dillon and Kirchner 1975; Dornbush, Anderson and Harms 1974; Loehr 1974; Uttormark, Chapin and Green 1974). Terrestrial nutrient losses are dependent on geology, soils, pH, precipitation, and other localized factors. Generalized expected loss of phosphorus and nitrogen from different land uses is included in Table 5-2. Omernik (1976) reports that streams draining agricultural watersheds have considerably higher mean nutrient levels than streams draining forested watersheds. Variations in stream nutrient concentrations, related to different land-use patterns, were more pronounced than variations in actual nutrient loading to lakes. Omernik suggests that this is due to differences in areal stream flow from different land use types.

Table 5-2. Expected loss rates of nitrogen and phosphorus from various sources (expressed as g/m^2 of land use area/yr).*

Source	Quantity of Nitrogen	Quantity of Phosphorus
Fertilized area	2.24	0.018
Citrus farms	0.11	0.135
Muck farms	0.85	0.018
Pastured area		
Unproductive cleared area	0.18	0.006
Forested area	0.24	0.008
Urban area	0.88	0.110

*After Shannon and Brezonik (1972); in Dunst et al. (1974).

Sargent (1976) has developed a watershed land use intensity index that illustrates some site specific factors important in determining lake nutrient loading levels. These factors are divided into those associated with lakeshore development (within 1000 feet of the lake) and those associated with upland development. Lakeshore factors include onsite soil absorption wastewater disposal systems, lakeshore frontage of developed lots, the proximity of roads that parallel the shoreline, and the amount of intensive public use areas. Land use factors in the upland include the amount of intensive development, forest cover, and agricultural or cleared open space.

Nutrient loading to streams and lakes can be reduced by improving land use practices. Structural and land treatment measures can be designed to control soil erosion and surface water runoff. Many state and Federal agencies (e.g. Soil Conservation Service, U.S. Department of Agriculture) promote these land management methods. Often land uses need to be restricted by regulatory means and can be implemented through voluntary actions, statutory regulations, educational programs, and government subsidies.

An example of a government program aimed at this non-point source water pollution is Section 208 of the Federal Water Pollution Control Act. The goal of this program is to develop comprehensive land use management plans to promote water quality.

5.1.2 Improved Waste Treatment

The treatment of wastewater is often used to reduce nutrient loading to streams and lakes. There are many types of treatment, but two general methods are municipal or industrial wastewater treatment plants and on-site wastewater treatment systems. At Cedar Lake, prior to the recently completed wastewaster collection system, all homes around the lake used on-site treatment systems. The perfomance of this type of system is adequate in some circumstances but a high probability of septic system failure is present around Cedar Lake due to the following conditions:

1) the soils have severe limitations (e.g. slow permeability),

2) the water table is often too high, and

3) many drain fields are located too close to the lakeshore.

In addition, poor installation, inadequate drain field size, and improper maintenance can adversely affect septic system efficiency (Otis 1979).

A U.S. Public Health Service Memorandum (1963) suggests that untreated wastewater or leachate from septic drain fields was a primary source of the sanitation and algae problem then associated with Cedar Lake. The present municipal sewage system has eliminated the active use of septic tanks by most homes and cottages around Cedar Lake.

Municipal and industrial wastewater treatment plants can be grouped into three categories according to design and the type of wastewater treatment performed - primary, secondary, and tertiary. Conventional wastewater treatment is designed primarily to remove solids and reduce the biochemical oxygen demand (BOD) of recipient waters, and is not designed to remove nutrients. Primary treatment removes solids by settling action and usually less than 15% phosphorus removal results (Convery 1970). Secondary treatment, such as conventional activated sludge systems, utilize biological processes and can remove up to 50% of the phosphorus. The most advanced wastewater treatment technology, tertiary treatment, adds chemical precipitation, adsorption, and other techniques and can remove up to 98% of the phosphorus.

A general comparison of the nutrient removal efficiency of different treatment processes is presented in Table 5-3. The actual percentage of nutrient removal varies from plant to plant due to system design, operating efficiency, and the nature of the wastewater.

Table 5-3. Comparison of nutrient removal processes for domestic waste.

Process	% Removal Nitrogen	% Removal Phosphorus
Ammonia stripping	80-98	
Anaerobic denitrification	60-95	
Algae harvesting	50-90	varies
Convential biological treatment	30-50	10-30
Ion exchange	80-92	86-98
Electrochemical treatment	80-85	80-85
Electrodialysis	30-50	30-50
Reverse osmosis	65-95	65-95
Distillation	90-98	90-98
Land application	varies	60-90
Modified activated sludge	30-50	60-80
Chemical precipitation		88-95
Chemical precipitation with filtration		95-98
Sorption		90-98

From: Dunst et al. (1974)

5.1.3 Treatment of Inflow

The treatment of inflowing water is a special case of wastewater treatment that can be used to correct a variety of water quality problems caused by inlet streams. Dunst et al. (1974) suggest that this method is appropriate when nutrient and sediment sources are too diffuse to be controlled individually and diversion is inappropriate, or where large-scale treatment is economically more efficient than small-scale systems.

Several methods that treat inlet streams exist but few have been well tested. Wastewater treatment, as described in the previous section, can be used to remove biological and chemical contaminants or reduce BOD. Some metal ions (e.g. aluminum, calcium, and iron) have been used to remove dissolved or suspended solids by forming low solubility phosphate compounds or by acting as an active phosphate-sorption site, resulting in a settleable floc. Aeration of inflowing water can drive off dissolved gases (e.g. N_2, NH_3, H_2S), oxidize organic matter and reduced elements (e.g. Fe, Mn, S) and cause floculation of suspended solids (Dunst et al. 1974).

Additional methods that may have potential in reducing nutrient and sediment inputs to lakes exist but have generally not been used in lake restoration projects (Dunst et al. 1974). For example, organisms growing in upstream reaches concentrate nutrients and can be harvested. If high nutrient concentrations are entering the lake through groundwater, metal ions injected into aquifers could reduce this source of loading. The shading of streams results in low stream temperatures. When this method is augmented with the channelization of the lake bottom of stratified lakes, nutrient inputs will occur below the epilimnion and thus be made generally unavailable to biological organisms.

5.1.4 Diversion

Diversion is the rerouting of nutrient-rich inflowing water outside of a lake's drainage basin. This technique is applicable in cases where nutrient inflows are greater than the assimilative capacity of the lake and where low nutrient levels exist in lake water and sediments (Sargent 1976). If high nutrient levels are already present in the lake system, improvement in water quality may be quite slow. Nutrient diversion alone may result in the degredation of recipient waters, and therefore is often accompanied by other techniques, such as wastewater treatment.

Dunst et al. (1974) report that this rehabitation technique is being applied in various situations with encouraging results, but that lake conditions have not always improved after diversion. A well established nutrient budget is quite important (and often lacking) in predicting the results of diversion.

A well documented, successful example of lake improvement resulting from diversion is Lake Washington, in the state of Washington (Edmondson 1970; 1972). After diversion of effluents, mean winter concentrations of phosphorus decreased 28%, nitrogen levels decreased 20%, and summer Secchi disc transparency increased from 1.0 to 2.8 meters.

The rehabilitation of Lakes Waubesa and Kegonsa, located near Madison, Wisconsin, involved the diversion of wastewater treatment plant effluent. The effects of the diversion channel constructed in 1968 on nutrient concentrations and algal blooms are discussed by Sonzogni and Lee (1972) and others. Inorganic nitrogen and soluble phosphorus influx decreased an estimated 75 to 86% respectively. Pretreatment algal populations in Lake Waubesa were over 99% blue-green species and one year after diversion a 25-75% reduction in these species was observed.

5.1.5 Product Modification

Product modification involves the alteration of consumer products to reduce nutrient loading to streams and lakes. This effort has currently been directed at chemical fertilizers and high-phosphate detergents. Nutrients in chemical fertilizers can readily enter streams, and research has been directed toward developing fertilizers that will not be leached as easily from the soil. Up to 40 - 70% of the phosphorus in municipal wastewater comes from detergents (Sargent 1976) and a large reduction in phosphorus loading could be realized by the elimination of this source. Current research is examining alternatives to phosphorus as an additive to detergents.

5.2 IN-LAKE METHODS TO ACCELERATE NUTRIENT OUTFLOW OR PREVENT RECYCLING

5.2.1 Dredging for Nutrient Control

Uses. The contribution of nutrients in lake sediments to lake productivity is imperfectly understood. Large scale lake dredging is a recent phenomenon and consequently only limited literature on its applicability to lake restoration is available. Lake dredging has been used as a restoration technique to control nutrients by (1) removing nutrient-rich sediments and uncovering a stratum that will not release appreciable nutrients, and (2) deepening shallow lakes so thermal stratification develops.

In shallow, unstratified lakes (like Cedar Lake), Dunst et al. (1974) report that the rate of sedimentary release is considerably elevated from that expected from diffusion along. Wind-induced circulation in shallow lakes can result in sediments being a major nutrient source (Haertel 1972). Recreational motor-boating may act in the same way (Yousef et al. 1979). Sediments may function as an important phosphorus source after other nutrient sources have been eliminated, particularly in lakes with a long hydraulic residence time and/or lakes that have received high nutrient loading for a long time (Theis and Depinto 1976).

Methods. Pierce (1970) has reviewed 49 lake dredging projects. He includes descriptions of various dredging methods and discusses sediment differences, hydrological considerations, and cost. Two general methods are used to remove lake sediments: mechanical dredging and hydraulic dredging. Mechanical dredging equipment is similar to land excavation equipment; draglines, shovels, or trenching machines are operated from land or from boats on the water surface. Hydraulic dredges use a pump to move sediments through a pipeline and then either to a boat or directly to a disposal site.

Lake dredging can be accomplished either underwater or by draining some portion of the lake. Dry excavation is usually restricted to areas that are easy to drain and refill. The most feasible dredging method for a particular lake is a function of physical factors of the lake basin, the project size, and geographic location of the lake. Pierce (1970) discusses dredging equipment use in detail. Some important considerations that determine the utility of different types of equipment include:

1) Access to lake and shoreline area and characteristics of the shoreline.

2) Location of and distance to disposal sites.

3) Area to be dredged.

4) Original water depth and volume of water present.

5) Final water depth required.

6) Volume of material to be removed.

7) Type of material to be removed.

8) Inflow to and outflow from the lake.

9) Possibility of lowering the lake level or emptying the lake.

10) Availability of water for lake refilling.

Environmental Concerns. There are numerous potential environmental concerns associated with dredging, including sediment composition, toxic substances, primary productivity, water temperature, nutrient concentrations, and disposal areas (Peterson 1979). The high turbidity that results from dredging, either at the dredge head or where dredge effluent from the disposal site is discharged, can cause several problems. Inorganic sediments that are resuspended generally settle at a rate dependent on particle size and density. Colloidal-sized particles can cause problems because they may remain in suspension for a long period of time. Organic particles are generally only slightly denser than water and are easily resuspended during dredging. This can subsequently result in oxygen depletion in lake water.

Synthetic organic chemicals (e.g. pesticides, herbicides, and industrial chemicals) and heavy metals are sometimes present in lake sediments and may be resuspended during dredging. For example, in Lake Vancouver, Washington, the unexpected presence of lindane and aldrin was discovered in the dredge effluent during a pilot dredge program (Dames and Moore 1977). Dredging makes these materials more available to aquatic food chains than if they remained buried in the sediments, because they become adsorbed to fine particles that settle slowly and consequently concentrate at the sediment-water interface where benthic organism activity is high.

Another serious concern is that increased nutrient levels can occur in lake water after dredging. Both phosphorus and nitrogen are adsorbed to fine sediment particles and may be released in large quantities during dredging. Nutrients released in this way remain in the water as either suspended or dissolved materials and are not transported to the dredge disposal site.

Primary production in a lake may be reduced because turbid water caused by dredging can result in decreased light penetration. This may also decrease oxygen concentrations. Increased suspended solids in surface waters also absorb more solar radiation and this causes increased water temperatures. Biological communities are sensitive to these light, oxygen, and temperature changes and respond to them in various ways.

Dredging disturbs fish spawning areas and removes a substantial number of benthic organisms that are important in fish food chains. Subsequently, there is a possibility that dredging can decrease fish productivity. However, Peterson (1979) cites evidence that dredging does not necessarily affect fish production adversely.

Costs. A critical factor often associated with dredging is the lack of adequate disposal sites. This problem is accentuated with larger dredging projects. The U.S. Army Corps of Engineers has developed a large information base on dredged material disposal in recent years and is the lead agency in issuing dredging disposal permits.

Dredging costs are influenced by many factors including: (1) the type and quantity of material to be removed, (2) the type of dredging equipment used, (3) the nature of the lake and lakeshore environment, and (4) the geographic location and mode of disposal (Peterson 1979). The disposal area is probably the most difficult cost to determine for the following reasons: (1) land is expensive in urbanized regions, (2) the disposal of dredge materials often conflicts with local land management practices, (3) recent wetland habitat legislation preserves wetland areas that formally were used for disposal, and (4) contaminated dredged materials require special sites on land behind dikes (Peterson 1979).

The above factors make it difficult to predict dredging costs for a lake by comparing various dredging projects. However, the most recent information reports average total dredging costs for Corps navigation projects in the Cedar Lake area as $2.08 per cubic meter. In five dredging projects in the Great Lakes Region, the cost range was $0.27 - $2.96 per cubic meter with a mean cost of $1.34 per cubic meter (Peterson 1979).

Case Study. Lake Trummen, Sweden is a well documented example of a successful dredging project. A meter of gyttja type sediment was removed from most of the lake bottom with the objective of reducing interstitial nutrient exchange from lake sediments to the water. The dredged material was disposed of in diked-off bays and in settling ponds. The effluent from the settling ponds was treated with alum to remove phosphorus and suspended solids before being returned to the lake. Bengtsson et al. (1975) report a decrease in total and orthophosphorus, and Kjeldahl-nitrogen in lake water after dredging. In addition, phytoplankton productivity decreased and phytoplankton diversity and Secchi disk transparency increased. Benthic organisms were not adversely affected (Anderson et al. 1975). Peterson (1981) provides several other case studies for review.

Large-scale dredging as a lake restoration technique, has usually been limited to littoral, embayment, and harbor areas which contain polluted or nutrient-rich sediments (Born 1979). Dredging must be practiced with caution due to potential adverse environmental consequences and possible high costs. Environmental hazards can be minimized with proper precautions and are usually of short duration. These disadvantages may be outweighted by longer-term benefits (Peterson 1979).

5.2.2 Nutrient Inactivation/Precipitation

Nutrient inactivation or precipitation within a lake consists of adding some material that will immobilize nutrients necessary for algal growth. Phosphorus is usually the preferred target for reasons presented earlier. Funk and Gibbons (1979) provide the most recent summary of nutrient inactivation. Included are a discussion of techniques, equipment, and costs, and a critical review of the advantages and disadvantages of this restorative action. Other useful publications are the U.S. Environmental Protection Agency (1973), Peterson et al. (1974), Dunst et al. (1974), and Cooke and Kennedy (1981).

Typically, nutrient inactivation procedures will: (1) change the chemical form of a nutrient, (2) remove nutrients from the photic zone, and/or (3) prevent recycling of nutrients within a lake (Dunst et al. 1974). Precipitation of material on the sediment-water interface can significantly inhibit nutrient exchange between the sediments and the water column. Metal ions, such as aluminum, iron, calcium, zirconium, and lanthium, can remove phosphorus from lake water by a combination of sorption, precipitation, and physical entrapment. Other materials, including ion exchange resins, zeolites, polyelectrolytes, aerobic lake mud, flyash, powdered cement, and clay have also been used as coagulants or adsorption agents. These substances can be distributed in a lake by dry broadcasting or manifold injection of a liquid solution.

Chemical precipitants were recently used successfully in Medical Lake (Bauman and Soltero 1978; Gasperino et al. 1979). This 64 hectare lake located in eastern Washington historically had massive algal blooms due to high nutrient concentrations. More than 930 tons of liquid alum were distributed on the lake with a homemade barge. The lake surface received four applications and the hypolimnion seven applications during August and early September of 1977. Results to date are encouraging - total phosphate concentrations and algae concentrations have been substantially reduced. Secchi disk transparency has increased. Medical Lake will continue to be monitored to determine the long-range impacts of nutrient precipitation.

Other similar lake treatments have been successful in Washington, Wisconsin, and Ohio. Funk and Gibbons (1979) report that treatment costs for nutrient inactivation projects ranged from \$150 per hectare to \$350 per hectare depending on the extent of pollution and differences in expenses (e.g. salaries, equipment, chemicals).

There are problems associated with nutrient inactivation as a restoration technique. According to Funk and Gibbons (1979), most treatments remain effective for only two or three years and thus nutrient inactivation alone cannot be considered a long-term solution. Other areas that require further study are the possible toxic effects of metal ions on the lake's biota that result from pH changes associated with the alum treatment (U.S. Environmental Protection Agency 1973).

5.2.3. Dilution/Flushing

Dilution and flushing are often used as synonyms (Welch 1979). They are, in fact, quite different processes. Flushing is a technique used to increase the flow through a lake and thereby flush out nutrient-rich waters. In this way, flushing emphasizes what goes out of the lake. Dilution, on the other hand, emphasizes what is left in the lake and implies a reduction in substance concentration.

In flushing, the replacement of lake water with water of similar nutrient concentrations may reduce algal concentrations if the water exchange rate approaches or exceeds the algal growth rate. In this way, a high flushing rate can reduce the algal standing crop without a resulting change in water quality. Flushing rates need to be quite high in order to accomplish this, however. For example, in Green Lake, Washington, a 104 hectare lake, a flushing time of approximately 2 days (∼800 cfs) was necessary to control problem algal species by physical washout (Welch et al. 1972).

The replacement of nutrient-rich lake water with nutrient-poor water can improve water quality by diluting nutrient concentrations in the lake. The success of dilution as a restoration technique is largely dependent on nutrient mass transfer processes. If the rate of nutrient inputs (i.e. bulk precipitation, surface water, groundwater, and nutrient exchange from sediments) is slow relative to low-nutrient water influx, water quality may be improved. The implementation of dilution/flushing as a restoration action depends on the availability of replacement water and the acceptability of discharging the displaced water.

Dilution/flushing projects have used both groundwater and surface water to replace existing lake water. The renewal of Snake Lake, Wisconsin consisted of pumping out lake water and allowing nutrient poor groundwater and precipitation to replace it. Initially most nutrient concentrations were greatly reduced in the lake but subsequent leaching of nutrients from the sediments negated these improvements. However, the feasibility of using groundwater in dilution/flushing lake restoration had been established.

Surface water has been used for dilution successfully in a number of projects. Green Lake, located in Seattle, Washington, is a 104 hectare, naturally eutrophic lake. Between 1962 and 1968, municipal water from Seattle, approximately eight lake volumes, were diverted into the lake (U.S. Environmental Protection Agency 1973). Substantial changes in water quality occurred. Phosphate concentrations declined, particularly during August and September when blue-green algal blooms had peaked. Considerable nitrate-nitrogen decreases were also observed. The blue-green algae standing crop was suppressed and a shift in dominance occurred, with the virtual elimination of Aphanizomenon flos-aquae (Dunst et al. 1974).

Some important factors that must be considered before a dilution/flushing restoration is implemented are enumerated by Dunst et al. (1974): (1) Dilution water must either contain lower nutrient concentrations than existing lake water or lack some nutrient that will become a limiting factor in the lake. A decrease in problem algal species biomass can be reduced in direct proportion to the amount of dilution water added. (2) Lake sediments may contribute nutrients to overlying water and can potentially offset any water improvement by dilution/flushing. This nutrient source may be critically important in shallow water and when dilution/flushing is discontinous. (3) The hydrodynamics and morphology of the lake must be investigated to fully assess the effects of dilution/flushing. For example, one dilution/flushing project failed due to poor placement of incoming replacement water.

According to Welch (1979), costs for dilution/flushing projects are highly variable and depend primarily on the availability of water and the presence of facilities to deliver it.

5.2.4 Biotic Harvesting

The harvesting of algae, macrophytes, and fish, which incorporate nutrients during their growth, has been used to increase nutrient outflow from lakes. Various methods, costs, and effectiveness are discussed in detail in U.S. Environmental Protection Agency (1973) and Dunst et al. (1974).

Biotic harvesting as a lake restoration technique is generally not funded by the Environmental Protection Agency's Clean Lakes Program, because of the temporary nature of the action. However, biotic harvesting may be included as a preliminary part of a permanent lake restoration project.

5.2.5 Selective Discharge

Selective discharge entails the release of anaerobic, nutrient-rich water from the hypolimnion of the lake (Dunst et al. 1974). This lake restoration technique is not suitable for Cedar Lake because the lake rarely stratifies.

5.2.6 Sediment Exposure and Desication

Nutrient release from sediments can be an important factor in the fertility of some lakes. Lake drawdown and subsequent sediment desication is a lake restoration technique aimed at decreasing this nutrient exchange. Lake drawdown has also been used to control submerged, rooted aquatic vegetation and as a means of deepening lakes by sediment consolidation.

The upper layer of sediment is where nutrient exchange generally occurs and thus is where chemical and/or physical changes are important (Lee 1970). Sediment exposure and desication alters the sediments in several ways including: (1) the oxidation of surface sediment layers, which upon refilling of the lake reduces the release of phosphorus, and (2) the physical stabilization of the unconsolidated, flocculent material, which can decrease nutrient exchange due to mixing (Dunst et al. 1974). However, accelerated decomposition of organic matter increases inorganic nutrient levels which may then be available for plant growth when the lake is refilled. In fact, drawdown followed by a period of dry fallowing is frequently used in fish culture ponds to increase fertility.

There is contradictory evidence for the effectiveness of this restoration technique. The net effect of the physiochemical processes, which both mobilize and bind phosphorus, is indefinite. In some lakes sediment exposure and desication has proved effective in controlling nutrient release from sediments, but this method is still in an experimental stage and investigation of site-specific sediment-water relationships need careful attention.

5.2.7 Lake Bottom Sealing

Lake bottom sealing is useful in reducing nutrient release from nutrient-rich sediments, and can be much less expensive than dredging in some cases. There are several covering types available which physically or chemically retard nutrient exchange, inhibit macrophyte growth, provide bottom stabilization, and/or reduce water loss via groundwater (Dunst et al. 1974).

Plastic and rubber sheeting has been used successfully in small areas as a physical barrier. Born et al. (1973) has demonstrated the utility of perforated black polyethylene covered with sand and gravel in controlling macrophytes and maintaining a recreational beach. The perforations in the sheeting prevent gas produced in underlying sediments from rupturing the sheeting. Lining materials and construction costs are reviewed by Kuman and Jedlicka (1973) for industrial applications.

Other materials being experimented with include flyash (Tenney and Echelberger 1970), clays and hydrous metal oxides (Wildung and Schmidt 1973; Browman and Harris 1973) and certain gels (Chung 1973).

Results from lake bottom sealing experiments indicate it is an effective method of lake restoration, but a number of questions require further study. The performance of different sealing agents, the effects of biological activity and lake mixing on the barriers, and the possible environmental disruption of lake benthic ecology need to be evaluated.

5.3 TREATING THE PRODUCTS OF OVERFERTILIZATION

Restoration methods that treat only the "symptoms" of lake eutrophication problems are not eligible for EPA Clean Lakes Program money and will not be discussed in detail here. A brief summary of existing technologies is presented because they can be useful as a part of a comprehensive lake restoration.

5.3.1 Physical Control

Mechanical circulation and/or aeration is commonly used to increase dissolved oxygen concentrations and thus improve fishery and other use potentials of lakes. Lake deepening by dredging, sediment consolidation, or dam modification can be used to correct sedimentation from culturally-induced erosion. Other physical controls, including the cutting and/or harvesting of macrophytes and algae, lake level manipulation, and other habitat manipulation techniques have been used to change lake conditions. Algal blooms, macrophyte problems, and undesirable fish populations have often been controlled chemically with algicides, herbicides, and piscicides.

5.3.2 Biological Control

Little attention has been devoted to the possibility of restructuring the biological communities of lakes as a direct approach to combating eutrophication. Shapiro et al. (1975) and Shapiro et al. (1982) summarize current understanding of biomanipulation techniques and provide evidence to support their use in lake restoration.

A holistic approach must be taken when considering biomanipulation. For example, if a goal of restoration is to reduce a certain objectionable species of phytoplankton, than it would be desirable to increase the number of zooplankton which prey on phytoplankton. The survival and longevity of zooplankton can be ensured by chemical additives to increase their fecundity or by reducing fish predation on them. Other methods for creating desirable shifts in algal species composition include: deliberate stocking of desired species, shifting the pH of a lake, and adding chlorine to depress phosphorus uptake of blue-green species.

Nutrient control can also be realized through biomanipulation. For example, phosphorus release from bottom sediments can be reduced by limiting macrophytes and certain species of fish (e.g. carp) which can act as nutrient pumps.

CHAPTER 6: FEASIBLE ALTERNATIVES

6.0 OVERVIEW

The restoration of a lake should be viewed, not from the narrow viewpoint of mitigating a single undesirable characteristic such as algal blooms, but from a broad perspective which encompasses the entire lake ecosystem, for it is the lake ecosystem which will be manipulated during a restoration effort. Cedar Lake's present condition materialized over a period of several decades. Likewise, lake restoration will likely take a number of years to complete and will require the combined cooperation of the entire community to succeed.

Historically, the community has shown interest in a clean Cedar Lake. Early actions to improve lake conditions resulted from ad hoc groups of concerned citizens. Community-level response to the deteriorating lake conditions did not coalesce until the planning of the area-wide wastewater treatment system.

The installation and operation of this sytem has brought about marked reduction in nutrient loading to the lake. As sewer lines were being laid, old septic system drainfield tiles, many of which discharged directly into the lake, were located and removed. This, along with the operation of the collection system, has eliminated over 60% of the pre-sewer external phosphorus loading to Cedar Lake (see Chapter 4). The sewer system installation also resulted in a significant decline in coliform bacterial levels in the lake.

The restoration of Cedar Lake requires this type of community involvement, but at an even greater scale. Since restoration is likely to cause some short-term inconveniences and will require long-term community planning, the total committment of the community is essential.

6.1 RESTORATION STRATEGIES

With the results of this study in mind, the following characteristics of Cedar Lake should be addressed by a restoration plan:

1) a high level of internal phosphorus loading due to a nutrient enriched layer of sediments to a depth of 30 cm;

2) high turbidity in the water column caused by the resuspension of flocculant sediment materials by winds, motor boats, and possibly fish;

3) poor water flow through, especially during the summer months when nutrient concentrations are highest;

4) a depressed fishery dominated by carp which also pump nutrients from the sediments into the water column;

5) seasonally dense algal blooms, characteristic of hypereutrophic lake conditions;

6) an N:P ratio which seasonally becomes low, favoring undesirable blue-green algal species.

It is important to keep these characteristics in mind when evaluating the feasible restoration alternatives which follow.

6.2 LAKE AND WATERSHED MANAGEMENT PRACTICES

There are a number of watershed management practices which would serve to compliment any restoration plan for Cedar Lake. These practices are discussed here and represent some low-cost options for lake improvement which are available to state and local officials.

6.2.1 Wastewater Treatment

At the present time there are approximately 100 dwellings in the immediate lake area which are not connected to the Lowell wastewater treatment system. These occur primarily in the area of the Cedar Lake Bible Conference Center along the western shore of the lake. Inadequately treated wastewaters from septic systems and the Utopia treatment plant were the greatest historical sources of phosphorus loading to Cedar Lake. Although the on-site system serving the Conference Center is new and water samples collected on July 7, 1982 showed no elevated levels of phosphorus or coliform bacteria, excessive seasonal loadings to the system along with seasonally high water tables can result in system failures. Careful maintenance and regular monitoring can help prevent failures, however, the best long term solution is for all wastewater sources around the lake to be hooked up to the collection system.

Integral to the effective operation of the wastewater treatment system is the maintenance of the collecting sewers. During periods of high rainfall, portions of the system become overloaded, forcing wastewater to physically lift off manhole covers to relieve the pressure. Flow of wastewater from manholes has been a problem at several locations, particularly at manhole #940 on Lauerman Road near the Pinecrest Marina. This manhole, within 100 feet of Sleepy Hollow Ditch, had discharge on March 3, March 29, April 12, and April 26, 1979 for a total of 58 hours. Manhole covers have been now sealed to prevent their displacement and a larger pump has been installed to relieve manhole discharge. However, overloads to the system are still occurring. For example, within hours of a 1.5" rain in November, 1982, base flow in the collection system increased from 550,000 gpd to 1,300,000 gpd (Charles Kouder, pers. comm.) No storm sewers are connected to the wastewater collection system but there is evidence that sumps and roof drains have been hooked up to the system without authorization.

A study is currently being conducted for the Town of Cedar Lake to determine if the heavier than expected flows are the result of infiltration or storm water runoff. Whatever the cause, the leakage of untreated wastewater into Cedar Lake in any amounts should be eliminated.

6.2.2 Stormwater Management

There is presently no centralized stormwater collection system operating for the Town of Cedar Lake. A visual inspection of the shoreline revealed several small (8") culverts and two large (3-4') culverts in place. No flow was observed discharging from any of these culverts during the course of the study.

If, as part of the expansion or centralization of the Town, a stormwater system is planned for a future date; detention and/or storage facilities should be included in the design plan to limit particulate and nutrient inputs to the lake.

6.2.3 Erosion Control

Although preliminary estimates of the sedimentation rate in Cedar Lake are rather low, sound erosion practices should be observed at all construction sites in the vicinity of the lake. These include observing appropriate setback requirements and maintaining adequate lot sizes. Harbor and channel deepening projects should also be closely scrutinized.

Plowing and land clearing in the watershed should be restricted to no closer than 100 feet from streams and drainageways which empty into Cedar Lake. Maintaining a buffer strip such as this will help keep sediments and nutrients on the land and out of the water.

6.2.4 Public Access

Before EPA will provide public funds for lake restoration projects, it requires that adequate public access facilities are available. Only one such access presently exists on Cedar Lake, an small acre parcel of state-owned land at the extreme north end of the lake. The access has a paved boat launching ramp but is otherwise unimproved. Local residents have expressed concern over the lack of restroom facilities at this site, which, during periods of heavy use, results in localized sanitation problems.

Although several privately-owned launch facilities are available to the public for a fee, these do not satisfy the access requirements. However, the acceptance of a Park and Recreation Plan in 1979 is expected to provide the necessary public access sites (Rhein et al. 1978).

6.2.5 Wetlands Management

The role of wetlands in trapping both phosphorus and suspended matter has received much attention in the literature. Wetlands serve as effective filters of phosphorus via four mechanisms: 1) physical entrapment, 2) microbial utilization, 3) plant uptake, and 4) adsorption (Hickok 1978). The percent removal of phosphorus by wetlands varies with loading rates, time of loading, hydrologic connection (e.g. riverine, lacustrine, etc.), type of vegetation, and soil characteristics. Because of this, literature values vary greatly. Some of the reported percent phosphorus removal values are: 77% by a 7 acre Minnesota wetland treated with urban stormwater (Hickok 1979); 50% by Brillion Marsh, Wisconsin, receiving domestic sewage (Sloey et al. 1978); 50% by Thereasa Marsh, Wisconsin (Klopatek 1978); and 30% by a cattail (Typha latifolia) dominated wetland in Wisconsin (Prentki et al. 1978). Hickok (1979) also reports 94% retention of suspended solids by the Minnesota wetland.

Although spring flow through Cedar Lake Marsh results in the transportation of some phosphorus and other nutrients to Cedar Lake from the winter decomposition of wetland vegetation, the net entrapment of these nutrients by the wetland cannot be overlooked. Approximately one-half of the drainage basin drains through the wetland and thus receives some 'treatment' before flowing into Cedar Lake. Over the years, this has probably kept nutrient loading to the lake significantly lower than it otherwise might have been.

Because of the tremendous nutrient reserves tied up in the soil and plant tissues, drained wetlands can release significantly greater levels of soluble phosphorus and nitrogen than when flooded (Klopatek 1978). For this reason, it makes practical sense, from a management point of view, to maintain Cedar Lake Marsh in its present condition. Filling, draining, or discharging into the wetland should be strongly discouraged (see Section 2.8).

As noted in Section 2.8, the wetland currently benefits the lake by providing a site where adsorbtion of nutrients can take place prior to their inflow into the lake. The wetland may retain its present role or may have alternative uses if utilized in a lake management project.

Possible uses include:

1. Disposal site for Cedar Lake sediments, if dredging is deemed feasible.

2. Seepage site for sediment elutriate.

3. Present uses with no modification.

4. Puchase by the state for use as an improved wildlife refuge or management area.

The first and second uses assume that the lake is dredged and that all permits needed for such use are forthcoming. Dredge material placed in Cedar Lake Marsh would significantly alter the flow regime of the marsh. While such an action would reduce the cost of dredging significantly, it is not advisable. The primary purpose of a dredging program would be to remove sediments that are high in nutrients. Placing these dredge materials in the wetland would permit rapid transport of the nutrients back into Cedar Lake, thereby making the dredging program ineffectual and, at the same time, reducing the wetland's capacity to assimilate nutrients and silt transported from the surrounding areas.

The second possible use, allowing the dredge elutriate to pass through the wetland, is more feasible than the first provided there is sufficient retention time within the wetland to retain the large quantity of water that is released. If the water is not retained for a sufficient period of time, the nutrients it contains will not be assimilated by the wetland. In addition, the water may resuspend some of the sediment within the wetland causing release of nutrients within the wetland soils. Our tests indicate that any disturbance of the wetlands soils may potentially release significant amounts of nutrients. As was noted in Section 2.8, the wetland already has some amount of channelized flow due to ditching within the wetland. This factor complicates the use of the wetland as an adsorption site for elutriate since flow in channels is generally too rapid to allow for nutrient adsorption.

If the elutriate is treated to remove suspended solids and nutrients prior to release into the wetlands, we would still be concerned with disturbance of the wetland vegetation, uprooting of plants, and resuspension of wetland soils. Only if the flow rate can be adequately controlled can this be recommended. It may be possible for the wetland to be used as a secondary route of flow whereby most of the flow is channeled (diverted) into an alternate route. With the large quantity of water released during dewatering of the dredged material, this consideration must be examined carefully to prevent erosion of streams flowing into the wetland and the lake.

The third possible use of the wetland, no modification, depends on the restoration technique adopted for Cedar Lake. If the lake is treated to modify the fishery, the wetland would need similar treatment to prevent migration of undesirable species of fish from the wetland. "No modification", merely means no intentional change in the wetland vegetation, flow regime, or size of the wetland.

The fourth possible use, puchase of the wetland for the purpose of preserving it or for use as a wildlife area should receive serious consideration. As stated in Section 2.8, the wetland presently serves the residents of Cedar Lake by capturing silt and nutrients that would otherwise reach Cedar Lake, thereby further reducing depth and contributing to problems of lake water quality. Use of the wetland to improve waterfowl habitat may be ill-advised. Any earthmoving or pond creation would likely release great quantities of suspended material and nutrients which could enter Cedar Lake. Alterations should be planned so as not to significantly decrease the retention time of water flowing through the wetland.

6.3 DREDGING

6.3.1 Introduction

Dredging as a restoration alternative for Cedar Lake was given a great deal of attention during this study, primarily because of strong public support for a dredging program and because early work indicated that internal recycling of phosphorus in Cedar Lake was significant. Dredging of Cedar Lake could be used to decrease internal phosphorus loading. Data collected in this study indicate that sediment nutrients are concentrated in the upper 30 cm of lake sediments in the deeper areas of the lake. The sand and gravel substrate of the more shallow areas (i.e. in less than 8-10 feet of water) are probably nutrient poor due to low cation exchange capacity of large-grained particles. The fine silts and clays in the deeper areas of the lake can concentrate large quantities of plant nutrients, as shown in the total nitrogen and phosphorus data from the winter of 1978-1979 (see Section 2.5). Sediment core analyses show that phosphorus concentrations decrease with depth, indicating that removal of the surface layer will reduce the potential for sediment phosphorus release.

This section of the report is designed to answer the fundamental questions involved with dredging. Some preliminary data have been gathered, both measured and estimated, and will be used in a discussion of: dredging locations and quantities, dredged material characteristics, and dredge disposal alternatives.

6.3.2 Dredging Locations and Quantities

A layer of finely textured particles having elevated phosphorus concentrations has been identified in the deeper areas of Cedar Lake and this strata is a prime target for dredging. Its thickness was measured to be approximately 0.3 to 0.4 meters in the sediment cores analyzed. The layer probably decreases in thickness in shallower waters and eventually disappears in around 8-10 feet of water where sand and gravel become the dominant lake substrate. Thus, the line on Figure 2-36 that approximates the transition zone between sand-gravel and silt-clay substrate also indicates the targeted dredging area ($1.8 \times 10^6 m^2$). The anticipated volume of potential dredged material is an area of approximately 1.8 million square meters with an average depth of 0.5 meters, or approximately 900,000 cubic meters (1.18 million cubic yards).

6.3.3 Dredged Material Characteristics

Chemical Characteristics. An analysis of the physical and chemical characteristics of Cedar Lake sediments is included in Section 2.5 and is summarized here using data for Core 1 as representative of the three cores analyzed (Table 6-1). Total phosphorus concentrations averaged 885 ug/g in the upper 20 cm and 476 ug/g from 20-50 cm. Total nitrogen concentrations average around 11 - 13,000 ug/g in the upper 50 cm and between 7500-8300 ug/g in the next meter. Lead, cadmium, copper, and zinc are found in highest concentrations in the upper 20 cm of sediment.

Table 6-1. Summary of general physical and chemical characteristics of sediments from Core 1 in Cedar Lake.

SEDIMENT DEPTH		METALS					NUTRIENTS		PHYSICAL CHARACTERISTICS	
cm.		LEAD	CADMIUM*	COPPER	ZINC	IRON	PHOSPHORUS	NITROGEN	ORGANIC MATTER	PARTICLE SIZE DISTRI- BUTION
		(ug/g)	(ug/g)	(ug/g)	(ug/g)	(ug/g)	(ug/g)	(mg/g)	% DRY WT.	% sand/ silt/clay
0- 20	mean	154.0	1.5	59.9	168.9	3160	885	11192	19	5/52/43
	range	(139.3-158.5)	(1.1-1.7)	(57.9-62.6)	(107.8-200.1)	(2966-3272)	(733-992)	(10733-12313)	(18.5-20.0)	silty clay
20- 50	mean	33.2	0.1	30.0	81.7	2976	476	12948	22	8/63/29
	range	(10.6- 69.6)	(0.0-0.2)	(27.3-35.5)	(75.3-106.2)	(2850-3069)	(218-361)	(10741-15958)	(19.7-24.2)	silty clay loam
50-100	mean	37.3	0.1	37.5	71.5	3284	438	8292	18	3/54/42
	range	(13.4- 50.0)	(0.0-0.3)	(27.2-41.0)	(58.5- 77.1)	(3001-3501)	(302-655)	(5912- 11245	(14.3-23.8)	silty clay
100-150	mean	23.1	0.8	34.0	74.1	3007	422	7444	11	0/49/51
	range	(18.7- 27.3)	(0.6-1.0)	(32.0-39.3)	(73.4-75.0)	(2834-3209)	(36/-518)	(6373-8779)	(10.0-12.9)	silty clay

NOTES:

*Cadmium values below 100 cm approach optimal detection limits. Low signal to noise ratios may distort values.

Physical Characteristics. A number of physical characteristics of potential dredged materials must be known in order to properly design a containment area to store the material as it dries. These include settling velocity, the speed at which dredged sediments settle after mixing with water; in situ void ratio, the ratio of pore spaces to sediment particles in the in-place sediments; and average void ratio, the ratio of pore spaces to sediment particles in the disposed material following dredging. These are all used to calculate the volume of dredged material to be stored, which compacts as it dries. Methods recommended by the U.S. Army Corps of Engineers (1978) were used to derive values for these parameters.

For these tests, an 8 inch diameter, 8.5 feet tall PVC sewer pipe, fitted with sample ports every foot, was used as a sedimentation column. A sediment-water mixture having 14% solids was added to the column and thoroughly mixed. After mixing, the fall of the sediment-water interface was recorded over time. These data are plotted as depth to interface vs. time. The slope of the constant settling zone of the curve is the zone settling velocity (Figure 6-1). Information required to design a containment area in which zone settling governs was obtained by using the calculations described in the following pages. These analyses give an estimate of the volume needed to allow sedimentation of 900,000 m^3 of dredged sediments, as well as the surface area required if the containment areas are filled to a depth of 4.6 m (15 ft.).

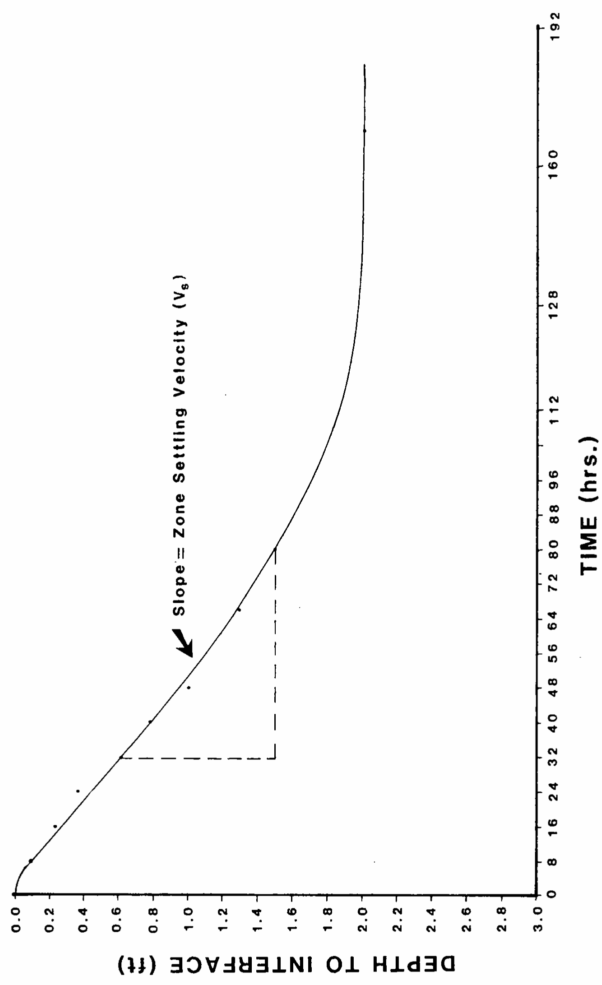


Figure 6-1. Settling curve for Cedar Lake sediments.

Physical Characteristics of Cedar Lake Sediments

water content of sediments	81%
solids content of sediments	19%
specific gravity (assumed)	2.6 g/cc

Settling Velocity (from data)

The settling velocity V_s is computed as the slope of the constant settling zone (straight line portion of the curve of depth to interface vs time) (Figure 6-1). The straight line portion lies between 32-80 hours. From this slope:

$$V_s = 0.024 \text{ ft/hr } (0.73 \text{ cm/min})$$

These data confirmed that the sediments were undergoing zone settling rather than flocculant settling. This distinction affects the calculations that follow.

In-Situ Void Ratio

$$e_i = \frac{WG_s}{S_d}$$

where G_s = specific gravity

S_d = degree of saturation (100% for sediments = 1.0)

W = water content

e_i = in-situ void ratio

$$e_i = \frac{(0.81 \text{ X } 2.69)}{1.0}$$

$$e_i = 2.18 \text{ g/cc}$$

Average Void Ratio

$$e_o = \frac{G_s \quad V_w}{V_d}$$

Where e_o = average void ratio of dredged material in the containment area at the completion of the dredging operation.

V_w = density of water (2.69 g/l)

V_d = dry density of solids (C_d = V_d) (245 g/l)

G_s = specific gravity of sediment solids

$$e_o = \frac{(2.69)(1000)}{(245)} = 10.98$$

Change in Volume in Disposal Area

The average void ratio is used to calculate the change in volume of fine grained sediments after disposal in the containment area (m^3).

$$V = V_i \quad \frac{e_o - e_i}{1 + e_i}$$

Where V = change in volume of fine grained sediments (m^3)

V_i = volume of fine grained sediments (m^3)

e_i = in-situ void ratio

and

V_i = 900,000 m^3 or 1.18 X $10^6 yd^3$

e_o = 10.98

e_i = 2.18

therefore $V = (900{,}000) \quad \frac{10.98 - 2.18}{3.18} \quad = 2.5 \text{ X } 10^6 m^3$

Estimate of the Volume Required for Dredged Material Disposal

$$V = V + V_i$$

Where V = volume of dredged material in the containment area at the end of the dredging operation

$$V = 2.5 \text{ X } 10^6 m^3 + 9.0 \text{ X } 10^5 m^3$$

$$V = 3.4 \text{ X } 10^6 m^3 \text{ or } 4.5 \text{ X } 10^6 yd^3$$

6.3.4 Dredging Time Requirements

The following calculations (Table 6-2) of the time requirements to dredge Cedar Lake are based on a Mud Cat Model MC-15, the hydraulic dredge presently owned by Lake County which would be used on Cedar Lake should a dredging program be implemented.

Table 6-2. Dredging time requirements.

Dredging depth:	0.5 m
Dredging volume:	900,000 m^3
Rate of removal:	50 m^3/hr (65 yd^3/hr)
Removal time required:	18,000 hrs
Total Project time - days	
@ 8 hrs/day (7 hrs operating, 1 hr maintenance)	2570 days
@ 16 hrs/day (14 hrs operating, 2 hrs maintenance)	1290 days
@ 24 hrs/day (22 hrs operating, 2 hrs maintenance)	820 days
Total Project time - years (April - November operation)[2]	
@ 8 hrs/day, 7 days/week	10.7 years
@ 16 hrs/day, 7 days/week	5.4 years
@ 24 hrs/day, 7 days/week	3.4 years

[1]From Dick Tillotson, Mud Cat Division, (per. comm.)

[2]Ice-free months

6.3.5 Dredged Material Disposal

Although the removal of Cedar Lake sediments is anticipated to be beneficial to the lake's long-term water quality, the disposal of dredged material could become a problem elsewhere. In recent years, increased understanding of the ecological importance of areas that were historically considered valueless (e.g. wetlands) has resulted in constraints on open-water and land disposal of dredged materials. As these attitudes have evolved, areas have become scarce for dredged material disposal and the concept of productive use of dredged material has been explored. Much of this work has been done by the U.S. Army Corps of Engineers Dredged Material Research Program (DMRP), and this discussion draws upon their research.

The use of a portion of the large wetland area at the south end of the lake as a disposal site may seem logical, but would be undesirable from an ecological standpoint and probably legally impossible. Currently, various alternatives to conventional dredged material disposal techniques exist. The creation of additional wetland areas around the lake would be possible with dredged spoils but this could be unpopular given the extensive development of the shoreline. Other considerations must be given to the proper sealing of an in-lake disposal area to prevent leaching of nutrients into the lake.

Upland dredged material disposal is a likely solution to what can be a difficult problem often associated with lake dredging projects. Numerous potential customers exist for dredged material (Table 6-3) in the Cedar Lake area and therefore sufficient demand could provide for use of the material. Of these users, the creation of wildlife habit/parkland development and agricultural uses will be discussed later.

6.3.6 Dredged Disposal Sites

The land use map (Figure 1-5) presented in Chapter 1 can be used to identify potential dredged material disposal sites. Considerable vacant/agricultural land is located near the lake on the west and north-west sides. Some of these areas have been proposed as potential public park sites (Figure 1-6) by the Northwestern Indiana Regional Planning Commission (Rhein et al. 1978), which would be a complementary use for these locations for landscaping.

A thorough screening of potential dredging disposal sites is required and should include the following criteria (Spaine et al. 1978):

1. site accessibility
2. available transport modes
3. environmental concerns
4. site characteristics
5. institutional concerns
6. public attitudes
7. compatibility with adjacent properties.

Various regulatory agencies need to be contacted concerning laws that may be involved in site selection (Table 6-4). Finally a cost-benefit analysis of remaining possible sites could be used to make the final decision. The factors that can be expected to greatly affect the cost of disposal are:

1. volume of dredged material
2. equipment needs
3. site topography
4. transport modes and distance
5. land
6. contractual agreements.

Soil Types. In locating disposal sites for Cedar Lake dredged material, particular attention was given to the type of soil, the extent of a soil type in a given area, and the physical and engineering properties associated with each soil type. A brief description of the geology and soils of the Cedar Lake watershed can be found in Section 1.5, Table 1-2, Figures 1-7 and 1-8. A more detailed description of each soil type in the proposed dredge disposal areas will be given here.

Table 6-3. Potential major customers for dredged material products.

CUSTOMER	USE
Raw material suppliers (sand and gravel mining and processing operations)	Material needs dictated by consumer being served. Requirements might be as simple as clean, organically free material or as stringent as separated coarses with a particular grain-size cutoff
Developers, construction firms	Landfill (classified and unclassified); subsidence fill; road embankments; earthfill dams; levees; shoreline restoration; aesthetic treatments (mounding, soil conditioner)
Mining industry	Fill and nutrient-rich cover for strip mines, quarries, undergound mines
Highway departments	Materials for road base; fill for embankments; sand to spread on icy roads
Asphalt and concrete plants	Sand for portland cement and asphaltic concrete mixes
Solid waste agencies and private firms	Cover for sanitary landfill operations
Environmental organizations and agencies (the Corps and state environmental and natural resources bodies)	Material for wildlife habitat creation (wetlands, bird islands)
Recreation agencies (local parks and recreation departments and the Corps)	Fill for parkland development; beach nourishment
Agricultural interests	Soil conditioner nutrient-rich cover; fill for erosion-prone fields and streambanks

From Spaine et al. (1978)

Table 6-4. Regulatory agencies and primary laws concerned with dredge disposal siting. From Spaine et al. (1978).

LAW	REGULATORY AGENCY
Rivers and Harbors Act of 1899	U.S. Army Corps of Engineers
Clean Water Act of 1977*	U.S. Army Corps of Engineers U.S. Environmental Protection Agency State Stream Pollution Control Board, Indiana State Board of Health
Fish and Wildlife Coordination Act of 1958	U.S. Fish and Wildlife Service, Indiana Department of Natural Resources
National Environmental Policy Act of 1969	All Federal agencies whose actions affect the human environment
State and local laws and ordinances governing land use, public work, material resources, health, etc.	State and regional land use planning agencies, Indiana Department of Natural Resources, numerous local governmental units

*Section 404

The thick deposits of silts and clays throughout the Valparasio Moraine are suited for land-fill type disposal areas. After compaction, these silty clay soils can be expected to exhibit permeabilities of less than 1x10-7 cm/sec. Therefore, the soils on which the proposed disposal sites are to be located form natural clay liners. These soils will prevent possible contamination of the groundwater aquifer. The soil types underlying the proposed disposal areas are: Morley silty clay loam, Morley silt loam, Markham silt loam, Elliot silt loam, and Pewamo silty clay loam.

Pewamo Series (Pc)

The Pewamo series consists of deep, poorly-drained, moderately fine-textured soils. These soils are nearly level and depressional. They exhibit 0-2% slopes. Typically the surface layer is very dark silty clay loam about 15 inches thick. The subsoil is about 27 inches thick, firm, and has few pebbles scattered throughout. The upper six inches of subsoil is a silty clay loam, the lower part is a gray clay loam. The underlying glacial till material is a clay loam.

A brief description of the Pewamo series horizon is as follows:

Ap - 0- 9 inches light silty clay loam
A1 - 9-15 inches light silty clay loam
B21t - 15-21 inches heavy silty clay loam
B22t - 21-30 inches heavy clay loam
B23t - 30-92 inches clay loam
C - 42-60 inches clay loam

Morley Series (MvB3, MuB)

This series consists of deep, moderately well-drained, medium textured, and moderately fine-textured soils. These soils exhibit 2-6% slope (MuB3 and MuB) in the areas covered by the proposed disposal sites. The surface layer is an eight inch thick silt loam. The subsoil extends to the depth of 44 inches, the uppermost seven inches is firm silty clay loam. The middle is a firm silty clay, and the lower 17 inches is a very firm silty clay that grades to a firm silty clay loam. The underlying material is calcareous silty clay loam.

A brief description of the Morley series horizon is as follows:

Ap - 0- 6 inches silt loam
A2 - 6- 8 inches silt loam
B1t - 8-12 inches light silty clay loam
B21t - 12-15 inches silty clay loam
B22t - 15-23 inches silty clay
B23t - 23-27 inches silty clay
B24t - 27-36 inches silty clay
B3 - 36-44 inches silty clay loam
C - 44-60 inches silty clay loam

Markham Series (MaB2)

This series consists of deep, moderately well drained, medium textured soils. The surface layer is a silt loam about 10 inches thick. The subsoil is about 30 inches thick. The upper 20 inches is a firm silty clay that grades to a gritty silty clay. The lower part of the subsoil is a firm silty clay loam. The underlying material is a firm gritty silty clay loam that contains many small pebbles. These soils exhibit 2-6% slopes.

A brief descrption of the Markham series horizon is as follows:

Ap - 0- 7 inches silt loam
A2 - 7-10 inches silt loam
B21t - 10-21 inches silty clay
B22t - 21-27 inches silty clay
B23t - 27-30 inches gritty silty clay
B3 - 30-40 inches gritty silty clay loam
C1 - 40-60 inches gritty silty clay loam

Elliott Series (El)

This series consists of deep, somewhat poorly-drained, medium textured soils, and are all nearly level. The surface layer is a gray-black silt loam 15 inches thick. The subsoil is about 11 inches thick, the upper four inches of which is a firm, heavy silty clay loam. The lower part is a silty clay. The underlying material is a silty clay loam containing many small pebbles. These soils are nearly level.

A brief description of the Elliott series horizons is as follows:

Ap - 0- 8 inches silt loam
A1 - 8-15 inches silt loam
B21t - 15-19 inches heavey silty clay
B22t - 19-26 inches silty clay
C1 - 26-32 inches light silty clay loam
C2g - 32-60 inches silty clay loam

The United States Department of Agriculture standards define silt as having particle sizes from 0.05 - 0.002 mm diameter. Clay is all colloidal material less than 0.002 mm. Eighty percent of each soil type mentioned above passed through a 200 mesh sieve (0.074 mm). Therefore all soil types underlying the proposed disposal areas contain at least 80% silt and clay. Further information on the soils of the Cedar Lake watershed can be obtained from the Soil Survey of Lake County (U.S. Department of Agriculture 1972).

Size Requirements. Disposal sites sizes were determined for two different options:

Option 1. All dredged materials would be placed in one area until the completion of the project.

Option 2. At the end of each dredging season, dredged materials would be dewatered and removed to another location.

In Option 1, the disposal site would have to be large enough to contain the entire volume of dredged materials produced. For an area designed to hold 4.6 m (15 ft) of dredged materials, the required area would be:

$$Ad = \frac{V}{Ddm}$$

where Ad = area required
V = volume of dredged material
Ddm = depth of dredged material

therefore $Ad = \frac{3.4 \text{ X } 10^6 m^3}{4.6 \text{ m}} = 7.4 \text{ X } 10^5 m^2$ or 73 hectares (180 acres)

Slightly smaller sites (140 acres) would also be suitable since the dredged materials volume decreases with dewatering and compaction.

In Option 2, the dredged materials could be removed annually from the disposal site. The same calculation can be made to determine the size but by using the maximum possible volume of dredged materials to be removed in one year.

Thus $\quad Ad = \frac{6.3 \times 10^5 m^3}{4.6\ m} = 1.37 \times 10^5 m^2$ or 14 hectares (34 acres)

with the dredge operating 14 hrs/day, 7 days/wk

or $\quad Ad = \frac{3.15 \times 10^5 m^3}{4.6\ m} = 6.8 \times 10^4 m^2$ or 7 hectares (17 acres)

with the dredge operating 7 hrs/day, 7 days/wk

Disposal Site Locations. Several factors were considered when deciding site identification for disposal areas. The major considerations were:

1. The size requirements (only vacant or agricultural land fits this category).

2. Engineering properties of the soils, particularly for their use as self-contained liners.

3. The costs associated with returning the water fraction to Cedar Lake following liquid-solid separation of the dredged material.

4. The cost of obtaining the land in the watershed.

5. The future development of the disposal area into a recreational park for the Cedar Lake community.

The calculated size of containment areas needed for Cedar Lake dredged materials under Option 1 above is 180 acres (73 ha). Each of the four areas identified as potential disposal sites is currently in an agricultural land use. The dominant land use on these sites is row crop production, mainly corn and soybeans. Sites 1, 2 and 3 are approximately 215 acres (87 ha) each, and Site 4 is approximately 150 acres (61 ha). All four proposed disposal sites under Option 1 are located west of the lake, inside the Cedar Lake watershed (Figure 6-2). Three sites under Option 2 have been identified. Each site is approximately 20 acres (8 hectares) in size.

By locating the disposal sites within the watershed, costs of pumping the dredged material to the disposal site and subsequent return of the water to Cedar Lake is kept at a minimum. Each of the proposed disposal sites have soils with suitable engineering characteristics to be used as containment pond construction material. The following sections have information concerning the subsequent use of dredged material after completion of a dredging operation.

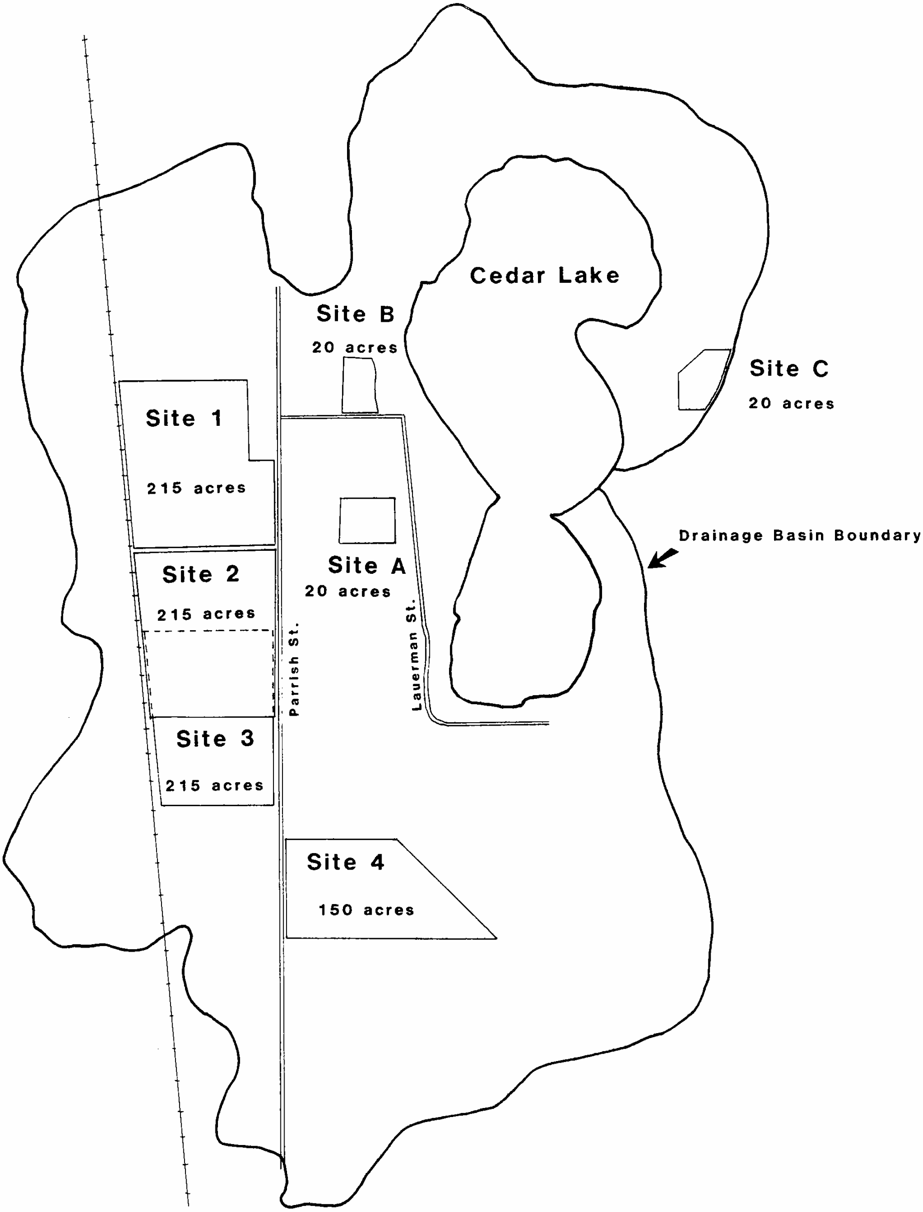


Figure 6-2. Location of possible dredged material disposal sites.

6.3.7 Habitat/Parkland Development with Dredged Material

Habitat/Parkland development involves the establishment of relatively permanent and biologically productive plant and animal habitats by using wildlife management and soil reclamation procedures at a particular disposal site (Smith 1978). At Cedar Lake, upland development merits consideration, as there is a need for additional habitat in this largely agricultural and urbanized area. Other advantages include the low cost and expected public acceptance.

Procedural guidelines for the planning and design of upland habitat on dredged disposal sites are outlined by Smith (1978) in Figure 6-3. If after evaluating particular sites and management techniques, upland habitat development remains feasible, implementation should involve local and state biologists and scientists. Techniques for the actual construction and development of upland habitat are discussed in other DMRP technical reports including Upland Habitat Development with Dredged Material: Engineering and Plant Propagation and Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations. Maintenance of developed habitats can be difficult, so low maintenance habitats are desirable. A private organization such as the Audubon Society or the Indiana Department of Natural Resources can potentially assume management responsibilities.

6.3.8 Agricultural Use of Dredged Material

Another potential alternative for the disposal of dredged lake sediments is their addition to marginal agricultural soils. The physical and chemical properties of some soils can be improved by the addition of dredged material so that water and nutrients are made more available to plants. In some circumstances, surface drainage can be improved with a layer of dredged material, thus reducing seasonal flooding and lengthening the growing season. Figure 6-4 lists factors that should be considered in determining the feasibility of specific dredged materials for agricultural purposes.

Gupta et al. (1978) provide an excellent review of this subject and develops some useful preliminary guidelines for the use of dredged material on agricultural lands. The sediments that have been analyzed from Cedar Lake are within (or very close to) desirable agricultural soil textures (Figure 2-30). Sediments in the shallower areas of the lake are more sandy, but could still be useful for agricultural purposes. These more coarsely-textured materials could be mixed with the finely-textured soils near the lake to form a loamy texture which would improve the existing physical and chemical characteristics for crop production.

Chemical analysis of the sediments is important to determine if pollutants are present in critical amounts. At Cedar Lake, the concentrations of some metals are elevated in the surface sediments, compared to the historical levels observed throughout the rest of

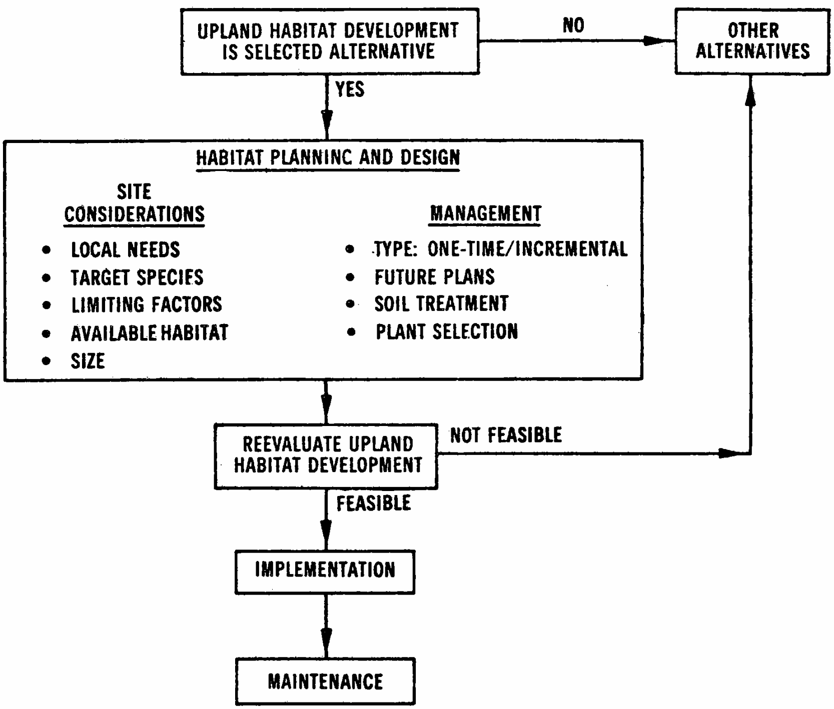


Figure 6-3. Procedural guidelines for selection of upland habitat development. From Smith (1978).

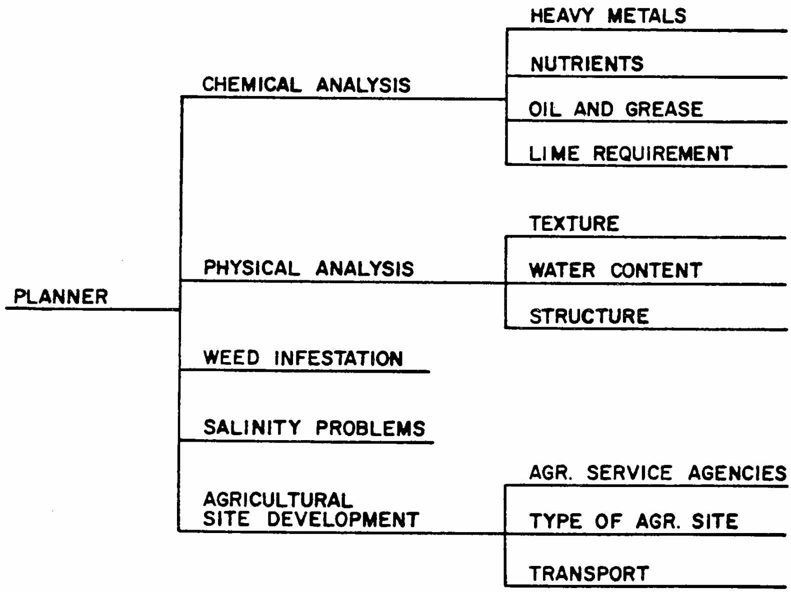


Figure 6-4. Decisional factors to be considered at the dredged material containment area before applying dredged material for agricultural purposes. From Spaine et al. (1978).

the cores. Spaine et al. (1978) argue that until Federal guidelines are set, perhaps the general guidelines used for wastewater sludge disposal on agricultural lands should be used for dredged material as well. The metal concentrations found in Cedar Lake sediments are below these guideline limits and therefore, these sediments would probably be suitable for agricultural land improvement projects.

Additional laboratory analyses (e.g. soil water retention, hydraulic conductivity) as suggested by Gupta et al. would be necessary to determine if other soil characteristics are acceptable.

6.3.9 Dredging Costs

Costs associated with a comprehensive dredging program for Cedar Lake were based on the needs and unit costs, identified in Tables 6-5 through 6-7.

Dredge operation costs are held steady for all options. The biggest variable affecting total program costs is the pumping distance to the disposal site. Extra booster pumps, operating costs, and labor are required for disposal sites located farther from Cedar Lake. Total program costs associated with each disposal site option are outlined in Tables 6-8 through 6-14.

Table 6-5. Needs and costs used to develop estimates for dredging costs.

EQUIPMENT & LABOR NEEDS	
- Mud Cat Dredge # MC-15 (can pump 3,000 ft)	
- small booster pump for each 3,000 ft of pumping	
- large booster pump for each 6,000 ft of pumping	
- 1 dredge operator	
- 1 shore helper for each booster pump	
- pipeline	
OPERATION COSTS	
- Mud Cat operation costs	$15.00/hr
- small booster pump	9.00/hr
- large booster pump	11.00/hr
- dredge operator	10.00/hr
- shore helper	8.00/hr
EQUIPMENT COSTS	
- Mud Cat # MC - 15	County owned
- pipeline	$10.00/ft
- small booster pump	$35,000
- large booster pump	$70,000

Table 6-6. Costs associated with dredged material disposal for Cedar Lake.

DISPOSAL COSTS - OPTION 1		
Land Acquisition		
- disposal	140 acres @ $3,000/acre	$ 420,000
- buffer	40 acres @ $3,000/acre	120,000
Dike Construction		
115,500 yds^3 @ $5.75/$yd^3$		664,125
Fencing		
12,000 L.F. @ $10.00/L.F.		120,000
Site Restoration		35,000
Contingency		100,000
	TOTAL	$1,459,125
DISPOSAL COSTS - OPTION 2		
Land Acquisition (disposal and buffer)		
20 acres @ $3,000/acre		$ 60,000
Dike Construction		
40,000 yd^3 @ $5.75/$yd^3$		230,000
Fencing		
3700 L.F. @ $10.00/L.F.		37,000
Site Restoration		5,000
Contingency		50,000
	TOTAL	$ 382,000

Table 6-7. Hauling costs under Option 2.[a]

Volume to be Hauled

Original dredged volume/yr (7 hrs/day) = 3.15×10^5 m^3

- assume 50% reduction in volume in one year

Volume to be hauled = 1.58×10^5 m^3

Cost Determination

\$38.00/hr (truck, driver, fuel) for a 20 ton truck ($18\ m^3$ capacity)

- assume 2 round trips/hr = 36 m^3/hr

Time needed to haul material

$$\frac{1.58 \times 10^5/m^3 \text{ material}}{36\ m^3/m} = 4389 \text{ hrs}$$

Hauling costs

4389 hrs @ \$38.00 hr = \$166,778

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[a]Endloader costs at disposal site have not been calculated.

Table 6-8. Disposal Site 1 costs.

Dredge operation 18,000 hrs @ $15.00/hr	$ 270,000
Large booster pump	
- purchase cost	70,000
- operating cost 18,000 hrs @ $11.00/hr	198,000
Small booster pump	
- purchase cost	35,000
- operating cost 18,000 hrs @ $9.00/hr	162,000
Labor (1 operator, 2 shore helpers) 18,000 hrs @ $26.00/hr	468,000
Pipeline 9,250 ft @ $10.00/ft	92,500
Disposal	
- land acquisition	540,000
- site construction	919,125
TOTAL	$2,754,625

Table 6-9. Disposal Site 2 costs.

Dredge operation	$ 270,000
Large booster pump	
- purchase cost	70,000
- operating cost	198,000
Small booster pump	
- purchase cost	35,000
- operating cost	162,000
Labor (1 operator, 2 shore helpers	468,000
Pipeline (10,572 ft)	105,720
Disposal	
- land acquisition	540,000
- site construction	919,125
TOTAL	$2,767,843

Table 6-10. Disposal Site 3 costs.

Dredge operation	$ 270,000
Large booster pump (2)	
- purchase cost	140,000
- operation cost	396,000
Labor (1 operator, 2 shore helpers)	468,000
Pipeline (12,158 ft)	121,578
Disposal	
- land acquisition	540,000
- site construction	919,125
TOTAL	$2,854,703

Table 6-11. Disposal Site 4 costs.

Dredge operation	$ 270,000
Large booster pump (2)	
- purchase cost	140,000
- operation cost	396,000
Small booster pump	
- purchase cost	35,000
- operation cost	162,000
Labor (1 operator, 2 shore helpers)	468,000
Pipeline (14,272 ft)	142,722
Disposal	
- land acquisition	540,000
- site construction	919,125
TOTAL	$3,072,847

Table 6-12. Disposal Site A costs.

Dredge operation	$ 270,000
Large booster pump	
- purchase cost	70,000
- operating cost	198,000
Labor (a operator, a shore helper)	324,000
Pipeline 6,000 ft @ $10.00/ft	60,000
Disposal	
- land acquisition	60,000
- site construction	322,000
Hauling	167,000
TOTAL	$1,471,000

Table 6-13. Disposal Site B costs.

Dredge operation	$ 270,000
Small booster pump	
- purchase cost	70,000
- operating cost	198,000
Labor (1 operator, 1 shore helper)	324,000
Pipeline (3,000 ft)	30,000
Disposal	
- land acquisition	60,000
- site construction	322,000
Hauling	167,000
TOTAL	$1,441,000

Table 6-14. Disposal Site C costs.

Dredge Operation	$ 270,000
Large booster pump	
- purchase cost	70,000
- operating cost	198,000
Labor (a operator, 1 shore helper)	324,000
Pipeline (5,000 ft)	50,000
Disposal	
- land acquisition	60,000
- site construction	322,000
Hauling	167,000
TOTAL	$ 1,461,000

6.3.10 Adverse Environmental Impacts

Environmental concerns associated with dredging are discussed in detail in Section 5-2. The fine texture of the Cedar Lake sediments to be dredged will cause high turbidity around the dredge head. Nutrient and toxic substances can be adsorbed to these particles which are not transported to the disposal site. A high BOD can be expected from organic matter that is resuspended in the water and thus oxygen depletion can occur. These types of environmental impacts can temporarily disrupt human activities (e.g. boating, swimming) as well as the biological communities existing in the lake.

6.4 PHOSPHORUS PRECIPITATION/INACTIVATION

Treatment of lakes with aluminum sulfate (alum) and/or sodium aluminate can be a successful method for removing phosphorus from the water column and for controlling its release from sediments. The process of using aluminum salts for phosphorus removal has long been used for the treatment of wastewater. This technology can be used as a step in the lake restoration process.

Phosphorus removal can occur by coagulation/entrapment of phosphorus-containing material, precipitation of aluminum phosphate ($AlPO_4$), or by sorption of phosphorus on the surface of the aluminum hydroxide floc. The long-term effectiveness of alum treatments will depend on the ability of deposited aluminum hydroxide to retain phosphorus at the sediment/water interface and thus curtail internal recycling of phosphorus. Secondary, short-term benefits can be realized if water column phosphorus concentrations are reduced by the treatment. If phosphorus is to be removed from the water column, the alum is surface applied. A floc develops and settles to the lake sediments. If nutrient-rich anaerobic sediments will be a significant source of phosphorus long after external sources are reduced, then alum treatments should be targeted against phosphorus exchanges at the sediment water interface. Alum is then applied directly at the sediment water interface causing the formation of a layer of colloidal aluminum hydroxide on the sediments. The colloidal layer can act as a barrier to the phosphorus that could be released from the internal cycling process.

6.4.1 Dose Determination

What is a sufficient dose to control P release from lake sediments for a prolonged period? The answer is not known but it is assumed that it is necessary to put as much aluminum hydroxide over the sediments as possible, short of causing adverse environmental impacts. Since excessive additions of aluminum will produce undesirable side effects (e.g. low pH and alkalinity, and high dissolved aluminum concentrations), an optimum dose would be that dose which reduces pH to 6.0. At lower pH, aluminum in the floc and other metals can dissolve. This optimum dose would maximize the amount of aluminum deposited over sediments as dictated by lake conditions (Kennedy and Cook 1982).

Alum $(Al_2(SO_4)_3 \cdot 14\ H_2O)$ doses for treating Cedar Lake were estimated from relationships between alkalinity and initial pH as reported in Kennedy and Cooke (1982). An optimum dose of approximately 165 mg/l of alum (15 mg Al/l) would be required to obtain a pH 6 in the treated Cedar Lake waters, having an initial pH of 8.0 and alkalinity of 120 mg/l as $CaCO_3$. With a lake volume of $8.44 \times 10^6 m^3$, approximately 1500 tons of dry alum or 565,000 gallons of liquid alum would be required for treatment. Treating Cedar Lake sediments to control phosphorus release could require substantially less alum than a water column treatment, since only the more flocculent silty clay sediment need be treated. This would reduce the lake area to be treated by about one-half.

Before alum could be applied to Cedar Lake, it is recommended that the optimum dose be calculated from lake conditions at the time of treatment, using the jar test procedure described in Cooke and Kennedy (1981). This laboratory procedure determines pH changes for various doses of alum. A dose determined using this procedure will greatly reduce the chances of excessive pH shifts during treatment.

6.4.2 Possible Adverse Environmental Impacts

Some of the possible negative effects of alum treatment include:

1. Possible toxic effects to fish and other aquatic organisms due to excessive levels of aluminum or other metals.

2. Formation of floc may have adverse effects on respiratory mechanisms of aquatic organisms or may interfere with the benthic environment by covering the sediments with settled floc.

3. A short period of high turbidity results following treatment.

4. Changes in pH necessary to obtain maximum effectiveness can have serious biological consequences.

The effect of alum treatment on conductivity, pH, alkalinity, and aluminum do not appear to be long-term. Following alum treatment of West Twin Lake, in Northeastern Ohio, pre-treatment levels of these parameters returned after one year (Cooke et al. 1978). However, sulfate concentrations were found to be twice the pre-treatment levels, but no negative effects were observed.

Aluminum toxicity does not appear to be a significant problem, as long as pH remains between 6 and 8 and/or the residual dissolved aluminum (RDA) is not allowed to reach levels in the area of 50 ug Al/l (Cooke and Kennedy 1981).

6.4.3 Treatment Costs

To achieve a dose of 15 mg Al/l in a whole-lake treatment, 565,000 gallons of liquid alum would be required to treat Cedar Lake. Total costs for this treatment would be approximately $445,000 (Robert Johnson, Aquatic Control, Inc., pers. comm.).

6.5 DILUTION/FLUSHING

Dilutional flushing, where nutrient-poor source water is pumped into a productive lake to dilute the existing nutrient-rich water, has been attempted on several lakes with some success. Dilution as a restorative technique requires that large amounts of water be diverted to the lake, and that the overflow or effluent water be disposed in some practical manner. In using this method, the replacement water must be readily available and there must be a convenient way of discharging the effluent.

Usually there are two approaches to dilution: 1) by introducing high quality water thus displacing an equal volume of poor quality water or 2) by completely removing the entire volume of the lake (or a significant portion) and then replacing it with an equal volume of higher quality water.

6.5.1 Feasibility Criteria

The applicability of implementing dilution flushing at Cedar Lake rests on the following criteria: 1) the availability of a local water source with TP and SRP concentrations less than Cedar Lake's; 2) the availability of a proper disposal site for overflow effluent water; 3) lake morphology constraints on flow-through capacity; 4) hydrological considerations (i.e. aquifer storage capacities, soil and bedrock porosity, and permeability); and 5) length of implementation time and potential for long-term benefits.

6.5.2 Evaluation

Presently it appears that implementation of this restorative technique is primarily constrained by the first of the aforementioned criteria. Tests conducted using this technique have generally required a flushing rate of about 3.5 total lake volumes per year. Usually groundwater or local drinking water supply reservoirs are used for dilution water, however these are not readily available or practical at Cedar Lake. The large volume ($2.53 \times 10^7 m^3$) of water required also does not appear to exist as surface water in the immediate area. In recent years groundwater has been pumped into Cedar Lake but this has not significantly decreased the nutrient concentrations. Instead, the groundwater pumping severely depleted nearby domestic water wells.

There has been much public input on the subject of springs discharging into Cedar Lake. Many residents recall encountering cooler water, evidence of springs, at numerous locations around Cedar Lake in years past. The public feeling is that sedimentation has filled in these springs and that the removal of the sediments would open up the springs, so that they could once again flow into Cedar Lake and help dilute the water pollutants.

Discussions with state experts suggests that while spring water likely did flow into Cedar Lake in the past in greater quantities than presently, the volume was insignificant when compared to the lake's total water budget. Springs would, therefore, not be an important dilutional mechanism for Cedar Lake's restoration. Evidence supporting this includes:

1. Cedar Lake's position near the surface and groundwater divide provides for little hydraulic gradient and thus little horizontal groundwater flow.
2. Domestic wells surrounding the lake likely contributed to the reduction in spring flow by lowering the water table.
3. The nearshore lake bottom areas where springs are most likely to occur, have little sediment accumulation and are composed largely of sand- and gravel-sized particles, through which water flows very well. Dredging these nearshore areas would do little to improve spring yields.

Case studies for evaluating dilutional pumping as a restoration technique have been conducted only on small lakes (12-200 acres). Lake morphology has been shown to have a large influence on the success of dilutional restoration (Dunst et al. 1974). The larger size of Cedar Lake and its particular morphology may present a problem for effectively using this procedure.

Any plan to utilize dilutional flushing would have to be structured around a scheme which requires the influent water to displace the lake water. Complete drawdown and replacement seems impractical. The presence of the dam at Cedar Creek, the level of the outflow stream (if gravitational drainage is desired), a large lake volume, the residential nature of the lake, and the effects of drawdown on the environment of Cedar Lake Marsh make drawdown of Cedar Lake undesirable.

One possible way to increase Cedar Lake's flushing rate would be to divert a former inlet back into the lake (see Figure 2-1). This inlet, near Cedar Creek on the east side of the lake, was diverted in the 1870's to help lower the lake level. The stream, though intermittant, drains an area of approximately 252 ha (622 acres). Such a diversion could increase the size of the current drainage basin by 14%.

Only one flow measurement could be made on this stream in 1979 (Table 2-1). Although the flow was low when measured, it is comparable to flow at stream Sites E and F at the same time. Local residents claim that discharge in this former inlet can be substantial following rain events. The stream drains predominantly forested land so water quality could be presumed to be at least as good as the other inlets to Cedar Lake.

The effectiveness of this diversion might be reduced due to the stream's close proximity to Cedar Creek. This could result in short-circuiting the inflow directly to the outflow, with little mixing. However, some benefits would be expected.

A reliable water budget and nutrient load should be determined for this stream before considering a stream diversion. Cost estimates for this action could not be estimated at this time.

6.6 BIOMANIPULATION

6.6.1 Concept

Most lake restoration programs designed to reduce the abundance of undesirable algae almost always are based on the premise that reduction of nutrient inputs, from both external and internal sources, is the key to success. An alternative strategy, termed biomanipulation, as opposed to nutrient manipulation, is beginning to show great potential alone or in combination with nutrient manipulation, in restoring eutrophic lakes. The thesis, as stated by Shapiro (1980), is that although phosphorus generally sets limits on the biotic responses of lakes, within these limits the kinds and magnitudes of the responses are functions of the structure of the biotic community. By carefully managing biotic communities, beneficial changes in the overall condition of eutrophic lakes are possible; most often at a fraction of the cost and effort involved in controlling phosphorus.

Figure 6-5 illustrates a simplified aquatic biotic food chain. In eutrophic lakes characterized by dense algal blooms, this chain is not properly balanced. In these cases the planktivores become so numerous that zoolplankton numbers are reduced, allowing for increases in algae. Benthivores may also be recycling nutrients that promote algal growth. Biomanipulation attempts to get this food chain in balance where it can be properly managed.

Biomanipulation strategies are illustrated in Figure 6-6. Although the end goal is reduction of algal biomass, none of the possible manipulations involve nutrients directly. Most deal with changing the quantitative and qualitative relationships among the biota so that the desired end is achieved.

Possible biomanipulations studied by Shapiro et al. (1982) include:

1. Elimination of bottom-feeding fish which, through their feeding activities, increase the nutrient concentrations and thereby the abundance of algae in lakes in which they abound.

2. Manipulation of algal populations to change species composition and/or reduce abundance by a) lowering pH, b) causing artificial circulation, c) stimulating activity of viruses that attack blue-green algae.

3. Direct manipulations of zoolplankton populations to increase abundance of herbivorous species and therefore grazing on the algae.

4. Indirect manipulations of zoolplankton (herbivores) by manipulating their predators -- planktivorous fish -- by a) experimental additions, b) elimination of planktivores by rotenone treatment, and c) elimination of planktivores by winter kill.

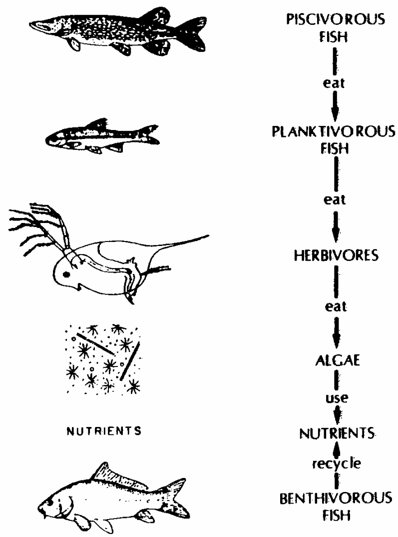


Figure 6-5. Simplified aquatic biotic food chain. From: Shopiro (undated).

5. Modifications in oxygen concentrations that may lead to large changes in algal populations by providing refuges for zoolplankters.

Of the above techniques, numbers 1 and 4 will be discussed in more detail regarding their application to Cedar Lake.

6.6.2 Experience From Other Lakes

Biomanipulation has been used successfully on a number of lakes, both in the United States and elsewhere in the world. Table 6-6 summarizes the results of a number of these experiences. Although

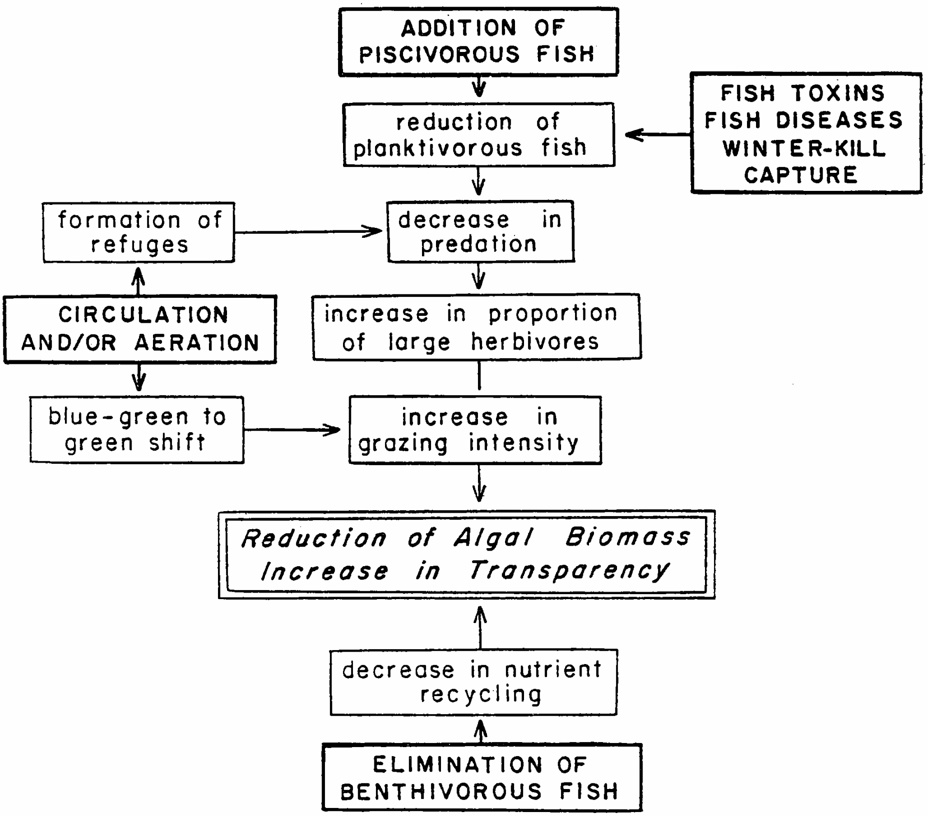


Figure 6-6. Biomanipulation strategies. From Shapiro et al. (1982).

different methods are used to increase the level of zoolplankter grazing on blue-green algae, the results are similar -- reductions in blue-green algae with accompaning reductions in chlorpohyll and increases in Secchi disk transparencies.

Researchers (Lynch and Shapiro 1979; Anderson et al. 1978) have also demonstrated that the reverse process occurs when planktivorous fish are added to lakes (Table 6-16).

6.6.3 Application to Cedar Lake

From previous sections of this report, it was demonstrated that Cedar Lake suffers from:

1. Dense blue-green algal blooms,

2. A fishery dominated by piscivores (black crappie) and benthivores (carp, channel catfish),

3. Low Secchi disc transparency,

4. High concentrations of total phosphorus, and

5. High concentrations of chlorophyll a.

These conditions indicate that Cedar Lake could benefit if the algal loss rate was increased by zoolplankton grazing. One way to do this would be to eliminate the planktivorous and benthivorous fish with rotenone and then restocking appropriately.

A fish renovation program for Cedar Lake was conducted in 1966 by the Indiana Department of Natural Resources. Approximately 2,300 gallons of rotenone were applied to the lake and neighboring wetlands, after which the lake was restocked with game fish. However, this effort was not successful in the long run because rough fish migrated back into the lake from downstream areas. There was also some indication that the contiguous wetlands were not treated throughly enough.

There is some supporting evidence which indicates that Secchi disk transparency in Cedar Lake increased following the fish renovation (Figure 6-7). In 1964, prior to the rotenone treatment, Secchi disk transparency measured 0.6 m (22 in). Three years following the treatment, in 1969, transparency was 1.1 m (44 in), a 100% improvement. The next measurements, after another five years had passed, show considerably less transparency. The lack of more data points make it difficult to establish a definite relationship. However, if the greater transparency was related to the fish renovation, then it is likely that transparency in the years immediately following the renovation was even greater than 1.1 m.

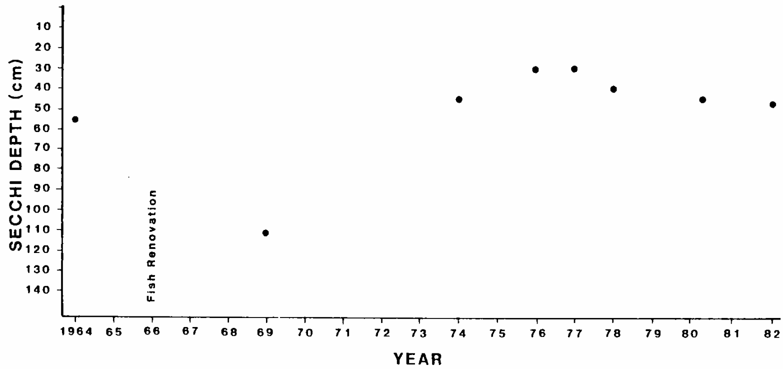


Figure 6-7. Comparison of Secchi disk transparencies in Cedar Lake before and after fish renovation. Measurements were made in July or August of the year indicated.

A new fish renovation program for Cedar Lake would require at least the following:

1. Total fish eradication in Cedar Lake and in all potential fisheries within its watershed.

2. Improvements to the outlet structure that would prevent rough fish from re-entering the lake. During the spring, water levels in the spillway pool are high enough to allow fish to jump or swim over the dam, into Cedar Lake. Possible solutions to this include: a) deepening the spillway pool, b) cleaning out Cedar Creek to increase flow so water does not back up, and c) coordinating discharge from Lake Dalecarlia downstream to keep water moving through the system so that it does not back up to Cedar Lake's dam. Improvements to the dam at Cedar Lake include the installation of a fish screen over the top of the dam, or installation of an overhanging, self-cleaning lip on the downstream side of the dam.

3. A public education program to keep rough fish from being introduced into the lake. This could require a ban on live bait fishing.

4. Restocking the lake with a proper balance of piscivores to planktivores.

Table 6-16. Some biomanipulation applications and their results.

Lake	Action	Results	Reference
Severson Lake, MN	Winter-kill	increased *Daphnia pulex*, blue-greens replaced by greens, 90% reduction in chlorophyll, increased transparency	Schindler and Comita (1972)
Lake Trummen, Sweden	Winter-kill	increased *Daphnia*, 90% reduction in algae	Bengtsson et al. (1975); Cronberg et al. (1975); Andersson et al. (1975)
Wirth Lake, MN	Rotenone	blue-greens replaced by greens, 66% reduction in algae, increased transparency, increased *Daphnia pulex*	Shapiro (1980)
Round Lake, MN	Rotenone; restocking	increased *Daphnia*, 130% increase in Secchi depth, reduced chlorophyll, decreased algal abundance	Shapiro and Wright (1982)
Lake Harriet	Reduction of *Daphnia*	5-10 fold increase in algal abundance	Shapiro (1979)
Bautzen Resevoir, GDR	Stocking with pike	Goal: reduction of Planktivorous perch	Benndorf et al. (1981)
Lake Norrviken, Sweden	Unstable stratification	increases zoolplankton, 60% reduction in chlorophyll	I. Ahlgren (1978); G. Ahlgren (1978)

Table 6-16 (cont.) Some biomanipulation applications and their results.

Lake	Action	Results	Reference
Enclosures	Bluegills added	Reduced Daphnia and other grazers, phytoplankton biomass increased by 21 times	Lynch and Shapiro (1979)
Lake Bysjon, Sweden (enclosures)	Benthivorous and zooplanktivorous fish added	17 fold increase in algal biomass	Andersson et al. (1978)

Since biomanipulation is a relatively new lake management technique, experience with fish restocking to hold algae in check is limited. However, in Round Lake, Minnesota, a 12.6 ha lake having a maximum depth of 10.5 m and a mean depth of 2.9 m, a fish renovation program has held blue-green algae in check for two years (Shapiro and Wright 1982). Table 6 - 17 shows the fish distribution in Round Lake before and after renovation. Restocked planktivores were limited to just bluegill while two species of piscivores, largemouth bass and walleye were stocked. Shapiro (pers. comm.) has suggested that channel catfish were not necessary to stock. They were stocked to provide an additional game species at the cost of nutrient resuspension due to their benthic nature.

6.6.4 Costs Associated With Biomanipulation

A 5% rotenone treatment at a minimum application rate of 1/2 gallon/acre foot would require 3,420 gallons of rotenone to treat Cedar lake alone (Bob Robertson pers. comm.). At $25/gallon the rotenone would cost $85,500. Wetlands and other possible sources of fish breeding stock in the watershed would also have to be treated with rotenone. This would raise the chemical costs further. To help keep rough fish from migrating back into Cedar Lake, Lake Dalecarlia may also require treatment. The costs incurred by the Indiana DNR for the restocked fish and the labor associated with the renovation are not charged to the local government when public lakes are renovated. The local government may be charged for all or part of the chemical costs.

Costs associated with outlet structure modifications can not be estimated at this time.

6.7 IN-LAKE STRUCTURES TO REDUCE WIND-GENERATED WAVES

As discussed elsewhere in this report, a considerable portion of the turbidity in Cedar Lake is a result of sediments being resuspended by wave generated water turbulance. Emergent vegetation and physical structures, such as gravel ridges or floating booms, can be used to disrupt wind stress at the water's surface. Submergent vegetation, on the other hand, can disrupt the circular "scooping" like flow of wind generated waves.

Weedbed areas of lakes Poygan and Butte des Morts in Wisconsin have singificantly better water clarity than unvegetated areas of the same depth (Sloey and Spangler 1977). Linde has reported sheet metal windbreaks are effects in reducing wave action to allow sumbergent vegetation to flourish (Sloey and Spangler 1977). Floating automobile tire booms have been used to break the wave stress at the water surface (Candle et al. 1977; Prince et al. 1977).

In Cedar Lake, open water barriers could be used to disrupt the two-mile long wind fetch (the distance over which winds travel unimpeded by structures) in the lake and thus help reduce

Table 6-17. Estimates of fish population density in Round Lake, MN.

	1980 (before renovation)[1]	1980 (restocked)
Planktivores[2]		
Bluegill Sunfish	2,200	4,000
Black Crappie	10,800	0
Green Sunfish	1,000	0
Piscivores		
Largemouth Bass	85	887
Walleye	0	918
Benthivores		
Black Bullheads	130,000	0
Channel Catfish	0	3,325

[1]estimated from counting dead individuals along 10% of the shoreline

[2]assumed to be primarily planktivorous based on size range of individuals

Source: Shapiro and Wright (1982)

wind-induced sediment resuspension. The most likely location for such a barrier is in the narrow constriction between the middle and south lobes of the lake. This constriction is approximately 370 meters (1200 feet) across with a maximum depth of 12 feet.

Construction of a rip-rap ridge across the lake at this point would require a great deal of material. For such a ridge to be effective, the top should be about two feet beneath the water surface. A break in the ridge would allow boats to pass through. Phragmites can be planted along the ridge to serve as an additional wave break.

A more feasible wave break might be a floating tire boom stretched across the constriction with a break in the middle to allow boats to pass. Such a boom is anchored to the bottom during the ice free months and can be towed to shore during the winter to mimimize ice damage.

Submerged aquatic plants could also be used to disrupt wave stress at the bottom of Cedar Lake. Light penetration would limit the potential range of such plants. Increased water clarity would allow submerged vegetation to survive at deeper depths and thus be more effective. Species that require only low light levels have not yet been identified.

6.8 DO NOTHING

To do nothing at Cedar Lake could also be considered as a feasible restoration alternative. With an estimated 63% of the former phosphorus loading to the lake now eliminated, the major source of water column nutrients is from the sediments. In time, there should be a net transfer of phosphorus to the sediments; in other words, internal loading should gradually decrease given that external loading does not increase. Due to the turbid conditions in the lake, caused by resuspension of flocculent sediments, by wind action and boats, the settling velocity for phosphorus is lower in Cedar Lake than in other lakes. This slows down the rate of net phosphorus flux to the sediments.

6.9 EXPECTED EFFECTIVENESS OF FEASIBLE ALTERNATIVES

Each of the feasible restoration alternatives discussed for Cedar Lake have different degrees of effectiveness for improving water quality. Dredging and nutrient inactivation are intended to accomplish water quality improvements by disrupting the internal movement or recycling of nutrients. The dilution/flushing technique deals with the accelerated outflow of nutrients. Biomanipulation controls algal blooms associated with high nutrient concentrations and reduces internal phosphorus cycling by benthivorous fish, while the reduced external loading to Cedar Lake and the natural phosphorous sedimentation rate work to reduce in-lake phosphorus concentrations. The do nothing approach assumes that in time, the internal cycling of nutrients will have a net movement to the sediments.

Because internal transport processes are poorly understood and nutrient pathways can vary considerably, quantitative assessment of the effectiveness of these restoration techniques is difficult (Uttormark and Hutchins 1978). However, restoration techniques can be qualitatively evaluated by input-output models such as the model used in the nutrient budget.

Vollenweider (1975) quantitatively defined the relationship between nutrient loading and trophic response and developed a relationship based on these components. The relationship relates total phosphorus loading as a function of the ratio of mean depth to hydraulic residence time (Figure 6-8). As mean depth (and thus volume) of a lake increases, the lake is able to assimilate higher loadings of phosphorus before an eutrophic condition results. Likewise, as hydraulic residence time increases (i.e., flushing rate decreases), smaller loadings can result in eutrophic conditions.

Boundary loading conditions are incorporated into the diagram which groups lakes into the three standard trophic states, i.e., oligotrophic, mesotrophic, and eutrophic. The lower boundary line ("permissable") designates the maximum phosphorus loading levels that a given water body could tolerate and still retain its oligotrophic character. The upper boundary line ("excessive") represents the phosphorus loading level above which a given water body would be characterized as eutrophic. This plot has been used

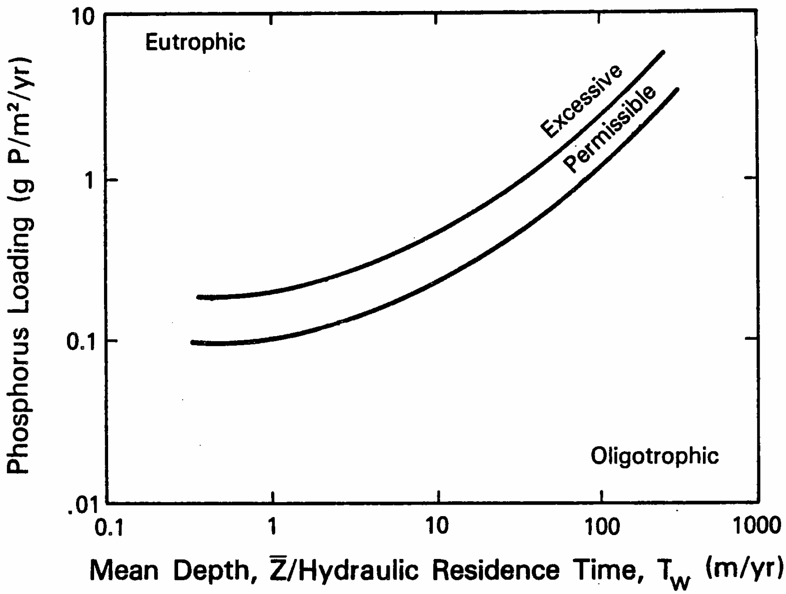


Figure 6-8. Nutrient loading/lake trophic condition relationship. From Vollenweider (1975).

widely as a decision-making tool for estimating the extent to which phosphorus loadings of eutrophic lakes should be reduced so that the lakes would achieve a more desirable trophic state (Uttormark and Hutchins 1978). Vollenweider's relationship will be used in this way to assess the relative effectiveness of the feasible alternatives discussed in restoring Cedar Lake.

6.9.1 Dredging

The removal of phosphorus-rich sediments from Cedar Lake can be expected to decrease phosphorus loading from sediments, which is estimated to be the major component of phosphorus loading in the lake; 86% for the "most likely" estimate (see Section 4.0). Phosphorus concentrations measured in the top 0.5 meter of sediments ranged from 380-930 ug/g. The removal of these upper sediments by dredging would expose a layer averaging approximately 400-500 ug/g.

The results of the sediment column phosphorus release experiments (see Section 2.5.5) indicate that dredging 0.5 m of

Cedar Lake sediment could reduce internal phosphorus loading from 2.05 $g/m^2/yr$ to 1.46 $g/m^2/yr$, a 29% reduction. Total loading (L_T) of phosphorus under the "most likely" estimate then becomes the sum of external loading (L_E) and internal loading (L_I) or 0.33 $g/m^2/yr$ + 1.46 $g/m^2/yr$ = 1.79 $g/m^2/yr$.

These loadings are plotted against mean depth (Z) over hydraulic residence time (T_W) on Vollenweider's curve in Figure 6-9. Total loading for Cedar Lake without dredging falls well above the excessive loading curve and respresents a eutrophic condition. Because of Cedar Lake's shallow mean depth, the relationship expressing mean depth over hydraulic residence time is quite small (Z/T_W) = 2.05). With dredging, mean depth increases slightly from 2.7 to 2.95 (Z/T_W = 2.23) and phosphorus loading decreases by 0.59 $g/m^2/yr$. The expression (L_E) still remains above the excessive loading curve. External phosphorus loading can be reduced further by measures which will eliminate estimated loading from the remaining septic systems (0.05 $g/m^2/yr$). External loading without septic systems becomes 1.74 $g/m^2/yr$ and would plot well above the excessive loading curve.

The combination of these measures (i.e., dredging and elimination of septic system loading) improves the position of Cedar Lake on Vollenweider's plot. The expressions as calculated, give a good direct approximation of the expected benefits to be derived from dredging and dredging with elimination of septic system loading.

6.9.2 Nutrient Inactivation/Precipitation

Quantifying the effects of restoration techniques, such as alum treatment, which disrupt nutrient cycling within lakes, is difficult because most input/output models only account for cycling in a gross sense by assuming net annual loss to the sediments -- seasonal changes are not addressed (Uttormark and Hutchins 1978). However, by specifying how the net annual phosphorus loss is altered, the expected benefits of alum treatment can be qualitatively evaluated.

By assuming that the phosphorus sedimentation rate (ρ) will be increased by a factor of "a", and that the sedimentation rate is a function of hydraulic flushing rate after Vollenweider (1976), the modified in-lake phosphorus concentratiuon following treatment can be compared to concentrations before by the following relationship (Uttormark and Hutchins 1978):

$$\frac{[P]'}{[P]} = \frac{1 + \rho}{a + \rho}$$

P = average in-lake phosphorus concentration before treatment
P'= in-lake phosphorus concentration after treatment
ρ = hydraulic flushing rate
a = factor by which phosphorus sedimentation rate increases

The ratio of "before" and "after" phosphorus concentrations provides a measure of the relative reduction in lake trophic state and can be related to phosphorus loading and plotted on Vollenweider's (1975) curve in Figure 6-9.

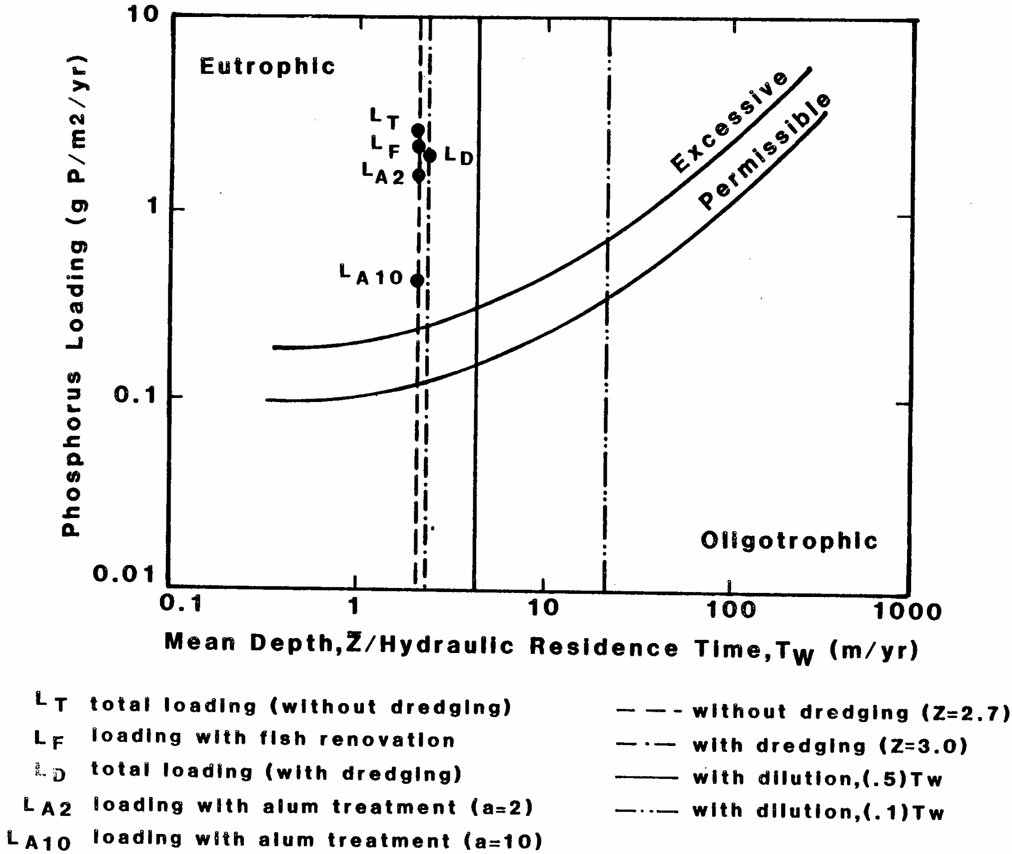


Figure 6-9. Plot of various predicted phosphorus loadings to Cedar Lake in Vollenweider's curves.

If the net movement of water column phosphorus to the sediments is assumed to double (i.e., a = 2) with alum treatment, the equation becomes:

$$\frac{[P]'}{(0.172)} = \frac{1 + 0.78}{2 + 0.78}$$

where [P] = 0.172 mg/l and ρ = 0.78 as determined previously (Section 3.2). Solving for [P]' yields:

$$[P]' = 0.112 \text{ mg/l}$$

Loading after alum treatment (L_A) then becomes:

$$L_{A2} = [P]' \, (V_s + q_s) \qquad \text{(Section 4.1, Equation 1)}$$

$$L_{A2} = (0.112)\ 13.80 = 1.55 \text{ g/m}^2\text{/yr}$$

When plotted on Figure 6-9, L_{A2} is still well above the excessive loading curve. By assuming a ten-fold increase in phosphorus loss to the sediments, loading after alum treatment (L_{A10}) becomes 0.41 g/m^2/yr. L_{A10} also plots in the eutrophic zone. As a result, alum treatment in Cedar Lake would have to result in a greater than ten-fold increase in the phosphorus sedimentation rate in order to decrease total loading of phosphorus to levels falling within the permissible range.

Although current research cannot accurately predict the actual increase in the rate of phosphorus sedimentation as a result of alum treatment, it seems unlikely that a greater than ten-fold increase could be maintained on an annual basis. In Long Lake, Washington (137 ha, mean depth = 2m, maximum depth = 3.7m) an alum floc was still in place and acting as an effective barrier to sediment phosphorus release two years following application, despite heavy recreational motor boating (Jacoby et al. 1982). On the other hand, Haertel (1972) recommends against the use of alum on shallow lakes where winds frequently stir up bottom sediments. On the basis of this, it may be difficult to effectively utilize alum treatment on Cedar Lake, except possibly in conjunction with another restoration technique.

6.9.3 Dilution/Flushing

The effect of dilution on in-lake phosphorus concentration is complex and may be influenced by potentially offsetting factors. When the inflow of water to a lake is supplemented with water from an additional source which has lower (but not zero) phosphorus content, the following changes are imposed on the system (Uttormark and Hutchins 1978):

(1) the areal and volumetric phosphorus loadings are increased;

(2) the average phosphorus concentration in the inflowing water is decreased; and

(3) the flushing rate is increased.

In addition, as in-lake phosphorus concentrations decrease, changes in the partitioning gradient between the sediments and overlying water could result in increased chemical release of phosphorus from the sediments.

Assume, for example, that the hydraulic flushing rate through Cedar Lake doubled (i.e., (0.5) T_W), then the relationship between mean depth and hydraulic residence time for a typical water year becomes:

$$\frac{\bar{Z}}{T_W} = \frac{2.7}{(0.5)\ 1.32} = 4.20$$

This new expression is also plotted on Vollenweider's curve (Figure 6-9). For comparison, a case where the flushing rate in Cedar Lake is increased ten-fold (i.e., (0.1) T_W) is also plotted.

In both cases, the expressions are shifted to the right on the plot, as hydraulic residence time decreases. This effectively allows for greater phosphorus loading before excessive loadings are reached. However, the decrease in residence time will be partially offset by the resulting increase in total phosphorus loading, unless water containing no phosphorus is used. Consequently, in determining the effectiveness of this method, the loading values (L_T, L_E, etc.) in Figure 6-9 cannot simply be horizontally displaced to the new $\bar{Z}/T_W$ expressions, but must be adjusted upward in relation to the increase in phosphorus loading.

Lakes with low flushing rates are identified as the worst candidates for improvement by dilution, because greater volumes of water, and thus greater increases in phosphorus loading, are necessary to achieve an optimal flushing rate (Uttormark and Hutchins 1978). In Cedar Lake, because of the apparent lack of an available local source of dilution water, large-scale dilution would not be feasible. However, increased flushing in Cedar Lake during the summer months, when outflow is minimal and the concentration difference between dilutional water and lake water is greatest, could result in noticeable improvements in water quality. The flushing rate could be increased some by the diversion of the former inlet back into Cedar Lake. Because of the steeper topography along the eastern side of the lake, this stream would respond rapidly to spring and summer rain events. The effectiveness of this additional input might be diminished due to the stream's close proximity to Cedar Creek, however it is estimated that an additional 0.17 X $10^6 m^3$ of water (3.4% of current yearly runoff) could discharge into Cedar Lake from this stream during a typical water year. This additional input would decrease the hydraulic residence time from 1.32 to 1.28 years.

6.9.4 Biomanipulation

Based on experiences with other lakes (see Table 6-16), 60-90% reductions in both blue-green algae and chlorophyll are possible with biomanipulation. Substantial increases in transparency are also likely.

Qualitative surveys have shown that the following zooplankton are present in Cedar Lake -- Daphnia, Bosmina, Nauplii, Chydorus -- and could form the breeding stock to recolonize the lake with zoolplankton. Large Daphnia (eg. Daphnia pulex) could be stocked in the lake, if needed, to increase grazing pressure on the algae.

Careful management following fish restocking will be necessary to ensure success. Rough fish migration controls will require frequent monitoring and cleaning or repairing as needed. A ban on live-bait fishing in Cedar Lake may also be necessary to ensure success.

6.9.5 In-Lake Structures

A floating tire boom across the narrow constriction of Cedar Lake could be effective in reducing wave action and thus reduce sediment resuspension on the leeward side. Efficiencies of up to 80% have been reported for 26 foot wide floating tire booms in 3 foot waves (Candle et al. 1977). Presumably, a narrower boom would be effective in breaking Cedar Lake's smaller waves, which can reach 1.5 feet in height.

6.9.6 Do Nothing

The do nothing alternative is the most difficult to assess for expected benefits because to do so adequately, a detailed working knowledge of the internal nutrient dynamics within Cedar Lake is necessary. A more reasonable approach would be to closely monitor the lake for improvements in water quality since the wastewater collection system became operational. After several years of data collection, inferences could be made concerning the rate of improvement, if any. This approach, unfortunately does not fit into known time frames for developing recommendations for restoring Cedar Lake.

A third approach is to assume a constant natural increase (a) in the phosphorus sedimentation rate (ρ) now that the wastewater collection system has greatly reduced external phosphorus loading. The level of improvement can then be assessed at 5 years, 10 years, and so on. Since we have no quantitative data on which to base "a", the values used here are somewhat speculative.

If we assume that the present rate of phosphorus sedimentation is a constant ten percent per year faster than pre-wastewater collection rates, then the following equation from Uttormark and Hutchins (1978) can be used:

$$\frac{[P]'}{[P]} = \frac{1 +}{a +} = \frac{1 + \rho}{1.1 + \rho}$$

By solving this equation for a number of years, it can be calculated that after 25 years at this rate of phosphorus sedimentation (a = 1.1), with other factors remaining the same, phosphorus concentrations in Cedar Lake would fall below those needed to sustain eutrophic conditions as defined by Figure 6-9. By assuming a twenty percent increase in phosphorus sedimentation rate (a = 1.2), thirteen years would elapse before Cedar Lake would attain a non-eutrophic status under the do nothing approach. If a fifty percent increase is assumed (a = 1.5), six years would be necessary.

Quantification of the change in phosphorus sedimentation rate in Cedar Lake would allow a more accurate estimation of expected benefits under the do nothing approach. Although the time frame for improvement in Cedar Lake appears long under this approach, it is relatively short when compared to the time it took for Cedar Lake to attain its present trophic state.

CHAPTER 7: RECOMMENDATIONS AND IMPLEMENTATION

7.0 RATIONALE

Although dredging has long been a popular restoration option with the Cedar Lake public, the expected benefits of dredging Cedar Lake (a 29% reduction in SRP release from the sediments) should result in lower water column phosphorus concentrations, however these concentrations will still be sufficient enough to cause dense blooms of blue-green algae, the major problem affecting public use of Cedar Lake.

The results of analyses conducted during this study along with literature available for lakes with similar problems all suggest that a biological approach to restoring Cedar Lake will have the greatest likelihood of achieving restoration goals. Biomanipulation would be most effective if used with several other in-lake management technqiues and the lake and watershed management practices discussed in Section 6.2, in a comprehensive restoration program consisting of the following steps (see also Figure 7-1).

7.1 RESTORATION PROGRAM

Step 1. Lake and Watershed Management Practices - Regardless of what action is taken at Cedar Lake, the lake and watershed management practices discussed in Section 6.2 should be adhered to. These include wastewater treatment, stormwater management, erosion control, public access, and wetlands management. See Section 6.2 for details.

Step 2. Fish Eradication - A total eradication of fish in Cedar Lake and other waters within its drainage basin should be conducted, preferrably in early fall. Total chemical costs for this eradication could approach $150,000, depending on the rates required and the area needing treatment. Some of these costs could be passed on to the local governments. Labor costs are generally not passed along.

Step 3. Fish Restocking - The goal of the fish restocking program is to have enough piscevores in Cedar Lake to keep planktivore numbers manageable. No benthivores should be re-stocked because of their role in the resuspension of sediments. The following species are recommended for stocking: Piscevores (largemough bass and walleye) and Planktivores (bluegill). The numbers and ratios of these species will be determined jointly with the Indiana Department of Natural Resources, Division of Fish and Wildlife. All species to be re-stocked are game species which will also stimulate sport fishing on Cedar Lake. The restocking should take place in late fall. Costs associated with labor and fish rearing are not generally passed along to local governments by the DNR.

Step 4. Outlet Improvements - Some improvements to the outlet structure at Cedar Lake (or the outlet structure at Lake Dalecarlia if it too is treated) will be required to prevent rough fish from re-entering Cedar Lake in the spring. It is recommended that representatives from the Town of Cedar Lake, Indiana DNR, and SPEA's research team meet to discuss the viable alternatives.

Step 5. Alum Treatment - Nutrient inactivation using alum would be a one time treatment, in the early spring following fish renovation. This would help provide optimal in-lake conditions for the fish and zooplankton. Expected benefits from this treatment include:

a. reduced water column phosphorus concentrations to help prevent algal blooms and thus increase water clarity, and

b. reduced water column suspended sediment concentrations by precipitation and adsorbtion of suspended material to the floc as it settles, and by creating a floc barrier at the sediment-water interface to help prevent resuspension of sediments.

These improvements will provide improved water clarity to aid the fish in feeding and will allow lower blue-green alga densities while the lake's zooplankton population recovers. Unfortunately, it is difficult to estimate how long the alum floc will remain in place (see Section 6.9.2). Such chemical treatment can be affective for several years, however, the goal for Cedar Lake is to provide benefits for one growing season, until the new biological system becomes established and balanced. It is recommended that alum be applied immediately above the silty-clay sediments which cover about one-half of the lake bottom (see Figure 2-36). Costs for this one-time alum treatment to Cedar Lake are estimated to be $225,000.

Step 6. Motorboat Speed Reduction - A reduction of motor boat speeds to trolling speed only from ice-out to July 1 of the treatment year is recommended to prevent motor boat turbulence from disturbing the alum floc at the bottom of the lake. This will allow the floc to remain in place and function for as long as possible. This is a one-time ban, however, a boat speed regulation that would limit speeds in shallow areas should be considered by Town officials.

Step 7. Ban on Live Bait Fishing - Following fish renovation, a total ban on the use of live bait for fishing is recommended for at least two years. This will prevent the inadvertant introduction of minnows and other planktivores that could interfere with fish and algae management objectives. Signs describing the ban should be placed at all marinas, public access sites, and private fishing areas around the lake. Notices should be placed in local and area newspapers as well.

7.2 PROGRAM COSTS

The restoration program for Cedar Lake as outlined, has the following costs associated with it:

Fish renovation: $150,000 - some or most of which will be funded up by the State of Indiana

Alum treatment: $250,000

Outlet improvements: costs unknown

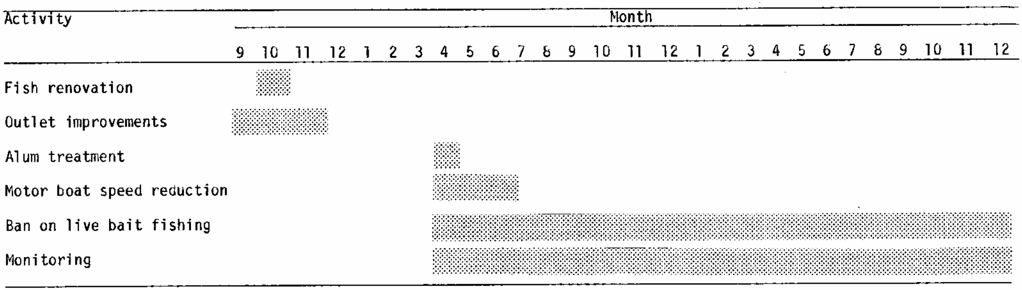


Figure 7-1. Proposed timetable for restoration activities on Cedar Lake.

CHAPTER 8: MONITORING PROGRAM

As a condition to receiving a Section 314 Clean Lakes Grant from the U.S. Environmental Protection Agency, a monitoring program is required to assess the effectiveness of the restoration efforts. It is recommended that the monitoring program for Cedar Lake comply with guidelines as stated in Paragraph (b) (3), Appendix A of Subpart H to Part 35 of Title 40 - Grants for Restoring Publicly Owned Freshwater Lakes (Federal Register 1979). The complete regulation is presented in Appendix G of this report, however, Paragraph 3 is reproduced here.

> "(3) A Phase 2 monitoring program indicating the water quality sampling schedule. A limited monitoring program must be maintained during project implementation, particularly during construction phases or in-lake treatment, to provide sufficient data that will allow the State and the EPA project officer to redirect the project if necessary, to ensure desired objectives are achieved. During pre-project monitoring activities, a single in-lake site should be sampled monthly during the months of September through April and biweekly during May through August. This site must be located in an area that best represents the limnological properties of the lake, preferably the deepest point in the lake. Additional sampling sites may be warranted in cases where lake basin morphometry creates distinctly different hydrologic and limnologic sub-basins; or where major lake tributaries adversely affect lake water quality. The sampling schedule may be shifted according to seasonal differences at various latitudes. The biweekly samples must be scheduled to coincide with the period of elevated biological activity. If possible, a set of samples should be collected immediately following spring turnover of the lake. Samples must be collected between 0800 and 1600 hours of each sampling day unless diel studies are part of the monitoring program. Samples must be collected between one-half meter below the surface and one-half meter off the bottom, and must be collected at intervals of every one and one-half meters, or at six equal depth intervals, whichever number of samples is less. Collection and analysis of all samples must be conducted according to EPA approved methods. All of the samples collected must be analyzed for total and soluble reactive phosphorus; nitrite, nitrate, ammonia, and organic nitrogen; pH; temperature; and dissolved oxygen. Representative alkalinities should be determined. Samples collected in the upper mixing zone must be analyzed for chlorophyll a. Algal biomass in the upper mixing zone should be determined through algal genera identification, cell density counts (number of cells per milliliter) and converted to cell volume based on factors derived from direct measurements; and reported in terms of biomass of each major genera identified. Sechi disk depth and suspended solids must be measured at each sampling period. The surface area of the lake covered by macrophytes between 0 and the 10 meter depth contour or twice the Secchi disk transparency depth, whichever is less, must be reported. The monitoring program for each clean lakes project must include all the required information mentioned above, in addition to any

specific measurements that are found to be necessary to assess certain aspects of the project. Based on the information supplied by the Phase 2 project applicant and the technical evaluation of the proposal, a detailed monitoring program for Phase 2 will be established for each approved project and will be a condition of the cooperative agreement. Phase 2 projects will be monitored for at least one year after construction or pollution control practices are completed to evaluate project effectivenes."

Regardless of whether Federal 314 funds are used to implement the restoration program recommended for Cedar Lake, some monitoring of restoration efforts is strongly recommended and may be essential for the successful restoration of Cedar Lake. Of critical importance is monitoring the outlet structure at Cedar Lake during high water levels to insure that rough or planktivorous fish are not getting back into the lake. Adherence to the live-bait fishing ban should also be regularly monitored by Conservation Officers, marina operators, and local citizens. The importance of preventing rough or planktivorous fish from being reintroduced into Cedar Lake cannot be over emphasized.

A yearly spot survey of the fish population structure should also be conducted. Ratios should be adjusted or alternative species selected if planktivore numbers increase beyond a reasonable amount. Regular sampling of the zooplankton and algal populations will also help in determining if a biological balance is being maintained.

CHAPTER 9: LITERATURE CITED

Agemiam, Haig and Chan, A.S.Y. 1976. Evaluation of extraction techniques for the determination of metals in aquatic sediments. The Analyst 101(1207): 761-767.

Ahlgren, G., 1978. Response of phytoplankton and primary production to reduced nutrient loading in Lake Norrviken. Verh. Int. Verein. Limnol. 20: 840-845.

Ahlgren, I., 1978. Response of Lake Norrviken to reduced nutrient loading. Verh. Int. Verein. Limnol. 20: 846-850.

American Public Health Association, American Water Works Association and Water Pollution Control Federation. 1971. Standard Methods for the Examination of Water and Wastewater, 13th edition. American Public Health Association, New York. 874 pp.

Anderson, J. 1972. Wet digest vs. dry ashing for analysis of tissue for trace metals. Atomic Absorption Newsleter 11: 88.

Andersson, G., H. Bergren, G. Cronbert and C. Gelin. 1978. Effects of planktivorous and benthivorous fish on organisms and water chemistry in eutrophic lakes. Hydrobiologia 59: 9-15.

Andersson, G., H. Berggren and S. Hamrin. 1975. Lake Trummen restoration project. III. Zooplankton, macrobenthos and fish. Verh. Int. Verein. Limnol. 19: 1097-1106.

Bailey, R.E. 1972. Late-and Postglacial Environmental Changes in Northeastern Indiana. Ph.D. Dissertation. Indiana University, Bloomington.

Banoub, M.W. 1975. Experimental studies on material transactions between mud and water of the Gnadensee (Badensee). Verh. Int. Verein. Limnol. 20: 466-474.

Barica, J. and F.A.J. Armstrong. 1971. Contribution by snow to the nutrient budget of some small northwest Ontario lakes. Limnol. Oceanogr. 16: 891-899.

Barnes, R.S. and W.R. Schell, 1973. Physical transport of trace metals in the Lake Washington Watershed. In, Cycling and Control of Metals, Proc. Environmental Resource Conference, Columbus, Ohio (Oct. 31-Nov. 2, 1972).

Bauman, L.R. and R.A. Soltero. 1978. Limnological investigation of eutrophic Medical Lake, Washington. Northwest Science 52(2): 127-136.

Bengtsson, L. 1975. Phosphorus release from a highly eutrophic lake sediment Verh. Int. Verein. Limnol. 19: 1107-1116.

Bengtsson, L. et al. 1975. Lake Trummen Restoration Project I, Water and Sediment Chemistry. Verh. Int. Verein. Limnol. 19: 1080.

Benndorf, J., D. Uhlmann and K. Putz. 1981. Strategies for water quality management in reservoirs in the German Democratic Republic. In Eutrophication: a global problem -- Part I. World Health Organization Water Quality Bulletin Volume VI. Environment, Canada. ISSN 0706-8158.

Birge, E.A. and C. Juday. 1934. Particulate and dissolved organic matter in inland lakes. Ecol. Monogr. 4: 440-474.

Black, C.A. (ed). 1965. Methods of Soil Analysis Part 1. Physical and mineralogical properties including statistics of measurement and sampling. American Society of Agronomy, Inc., Madison, Wisconsin.

Blatchley, W.S. 1897. The Geology of Lake and Porter Counties, Indiana. Indiana Department of Natural Resources Annual Report, Indianapolis.

Born, S.M. 1979. Lake Rehabilitation: Status Report. Environmental Management 3(2): 145-153.

Born, S.M., T.L. Wirth, J.O. Peterson, J.P. Wall and D.A. Stephenson. 1973. Dilutional Pumping at Snake Lake, Wisconsin. Technical Bulletin No. 66. Wisconsin Department of Natural Resouces, Madison, Wisconsin.

Brooks, R.R. and M.G. Rumsey, 1974. Heavy metals in some New Zealand commercial sea fisheries. New Zealand Jour. Mar. Freshwat. Res. 8(1): 155-166.

Candle, R.D. and W.J. Fischer. 1977. Scrap Tire Shore Protection Structures. Engineering Research Department, The Goodyear Tire and Rubber Company, Akron, OH.

Chow, V.T. (ed). 1964. Handbook of Applied Hydrology, A Compendium of Water-Resource Technology. McGraw-Hill Co., New York.

Chung, N.K. 1973. Investigation of use of gel material for mine sealing. EPA-R2-73-135, U.S. Environmental Protection Agency, Washington.

Convery, J.J. 1970. Treatment techniques for removing phosphorus from municipal wastewater. Water Pollut. Control Res. Ser. No. 17010-01/70. U.S. Gov. Printing Office, Washington, D.C.

Cooke, G.D., M.R. McComas, D.W. Waller and R.H. Kennedy. 1977. The occurance of internal phosphorus loading in two small, eutrophic, glacial lakes in northeastern Ohio. Hydrobiologia 52(2): 129-135.

Cooke, G.D. and R.H. Kennedy. 1981. Precipitation and Inactivation of Phosphorus as a Lake Restoration Technique. EPA-600/3-81-012. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, OR.

Cooke, G.D., R.T. Heath, R.H. Kennedy and M.R. McComas. 1978. Effects of diversion and alum application on two eutrophic lakes. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Oregon.

Crecelius, E.A. and D.Z. Piper. 1973. Particulate lead contamination recorded in sedimentary cores from Lake Washington, Seattle. Environ. Sci. Techn. 7: 1053-1055.

Cronberg, G., C. Gelin and K. Larsson. 1975. Lake Trumen restoration project. II. Bacteria, phytoplankton and phytoplankton productivity. Verh. Int. Verein. Limnol. 19: 1088-1096.

Dames and Moore. 1977. Vancouver Lake Rehabilitation. Prepared for the Regional Planning Council of Clark County.

Davis, M.B., L.B. Brubaker, and T. Webb III. 1973. Calibration of absolute pollen influx. In, H.J.B. Birks and R.G. West, (eds.), Quaternary Plant Ecology, the 14th symposium of the British Ecological Society. Blackwell Scientific Publications, Oxford.

Dillon, P.J. and F.H. Rigler. 1974. The phosphorus-chlorophyll relationship in lakes. Limnol. Oceanogr. 19(6): 767-773

Dillon, P.J. and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from watersheds. Water Research 9: 135-148

Doggett, D. 1950. Hydrology studies tell the story - Part 3. Outdoor Indiana. 17(9): 6-10.

Dornbush, J.N., J.R. Anderson and L.L. Harms. 1974. Quantification of pollutants in agricultural runoff. EOA Environmental Protection Technology Series EPA-660/2-74-005. U.S. Environmental Protection Agency, Washington, D.C.

Dudley, J.G. and D.A. Stephenson. 1973. Nutrient Enrichment of Ground Water from Septic Tank Disposal Systems. Upper Great Lakes Regional Commission.

Dunst, R.C., S.M. Birn, P.D. Uttormark, S.A. Smith, S.A. Nichols, J.O. Peterson, D.R. Knauer, S.L. Serns, D.R. Winter, T.L. Wirth. 1974. Survey of Lake Rehabilitation Techniques and Experiences. Technical Bulletin No. 75. Wisc. Dept. of Natr. Resources, Madison.

Edmondson, W.T. 1970. Phosphorus, nitrogen and algae in Lake Washington after diversion of sewage. 169(3946): 690-691.

Edmondson, W.T. 1972. Nutrients and phytoplankton in Lake Washington. Nutrients and Eutrophication Special Symposia, Amer. Soc. of Limnol. and Oceanogr., Inc. 1: 172-193.

Ellis, B. and K.E. Childs. 1973. Nutrient Movement from Septic Tanks and Lawn Fertilization. Technical Bulletin No. 73-5. Mich. Dept. of Natural Resources, Lansing.

Entranco Engineers. 1978. Restoration Analysis of Wapato Lake. Entranco Engineers, Bellevue, WA.

Environmental Divices Corporation (ENDECO). 1980. ENDECO Type 2100 SLDS "Septic Snooper TM"; Operation Manual. Marion, Massachusetts.

Evert Kincaid and Associates, Inc. 1964. Special Study: Cedar Lake and Environs. Chicago.

Federal Register. 1979. Grants for Restoring Publicly Owned Freshwater Lakes - State and Local Assistance, 40 CFR Part 35. Federal Register, 44(20): 5685-5693. January 29, 1979.

Fillos, J. and W.R. Swanson. 1975. The release rate of nutrients from river and lake sediments. Journal of the Water Pollution Control Federation 47: 1032-1042.

Fogg, G.E. 1975. Algal Cultures and Phytoplankton Ecology. University of Wisconsin Press, Madison.

Förstner, Ulrich. 1977. Metal concentrations in freshwater sediments - natural background and cultural effects. In, Golterman (ed.), Interactions between sediments and freshwater. Proceedings of an International Symposium held in Amsterdam, The Netherlands.

Frant, S. and I. Kleeman. 1941. Cadmium food poisoning. Jour. Amer. Med. Assn. 17: 86.

Funk, W.H. and H.L. Gibbons. 1979. Lake restoration by nutrient inactivation. In, Lake Restoration. U.S. Environmental Protection Agency. U.S. Government Printing Office. Washington, D.C.

Gallepp, G.W. 1979. Chironomid influence on phosphorus release in sediment-water microcosms. Ecology 60(3): 547-556.

Gasperino, A.F., G.R. Keizer and R.A. Soltero. 1979. Preliminary findings of Medical Lake restoration. In, Lake Restoration. U.S. Environmental Protection Agency, U.S. Government Printing Office, Washington, D.C.

Giesey, J.P. and J.G. Wiener. 1977. Frequency distribution of trace metal concentrations in five freshwater fishes. Trans. Amer. Fish. Soc. 101: 544-547.

Goodwin, R.H. and W.A. Neiring. 1975. Inland Wetlands of the United States. Natural History Theme Studies, No. 2, National Park Service.

Governor's Water Resources Study Commission. 1978. Report of Committee on Water Availability and Quality. Indianapolis.

Great Lakes Basin Commission. 1975. Great Lakes Basin Framework Study. Appendix 21 - Outdoor Recreation. Public Information Office, Great Lakes Basin Commission, Ann Arbor.

Great Lakes - Illinois River Basins Project. 1963. Memorandum Report: Cedar Lake, Lake County, Indiana - Sanitation and Algae Problem. U.S. Dept. of Health, Education and Welfare, Chicago.

Grimwood, C. and T.J. McGhee. 1979. Prediction of pollutant release resulting from dredging. Journal WPCF 51(7): 1811-1815

Gupta, S.C., W.E. Larson, R.G. Gast, S.M. Combs and R.H. Dowdy. 1978. The Agricultural Value of Dredged Material. U.S. Army Corps of Engineers Technical Report D-78-36, Vicksburg.

Haertel, L. 1972. Ecological factors influencing production of algae in northern prairie lakes. S.D. State Univ., Water Resour. Inst., Completion Rep., Proj. No. A-208-SDAK.

Haertel, L. 1976. Nutrient limitations of algal standing crops in shallow prairie lakes. Ecology 57: 664-678.

Hale, S.S. 1975. The role of benthic communities in the nitrogen and phosphorus cycles of an estuary. In, F.G. Howell, J.B. Gentry and M.H. Smith (eds.), Mineral Cycling in Southeastern Ecosystems. U.S. Energy Research and Development Administration Symposium Series.

Hargrave, B.T. and L. Kamp-Nielsen. 1977. Accumulation of sedimentary organic matter at the base of steep bottom gradients. In, Golterman (ed.), Interactions Between Sediments and Fresh Water. Proceedings of an International Symposium Held in Amsterdam, the Netherlands.

Hartke, E.J., J.R. Hill and M. Reshkin. 1975. Environmental Geology of Lake and Porter Counties, Indiana - An Aid to Planning. Environmental Study 8, Geological Survey Special Report II. Indiana Dept. of Natural Resources, Bloomington.

Harve, G.N., B. Underdal and C. Christiansen. 1973. Cadimium concentrations in some fish species from a coastal area in southern Norway. Oikos 24: 155-157.

Hickok, E.A. 1979. Wetlands and organic soils for the control of urban stormwater. In, Lake Restoration. Proceedings of a National Conference, held in Minneapolis, MN. U.S. Environmental Protection Agency, Washington.

Holdren, G.C., Jr. and D.E. Armstrong. 1980. Factors affecting phosphorus release from intact lake sediment cores. ES&T 14(1): 79-87.

Holdren, G.L. 1974. Measurement of interstitial inorganic phosphorus and phosphorus release from lake sediment. Ph.D. Dissertation. Univ. of Wisconsin, Madison.

Hutchinson, G.E. 1957. A Treatise on Limnology. Volume 1, Part 1 - Geography and Physics of Lakes. John Wiley and Sons, New York.

Indiana Department of Natural Resources. 1979. Photographs on file at the Division of Water, Indianapolis.

Indiana State Board of Health. 1975-78. Water Quality Data for Cedar Lake. (unpubl.).

Jacoby, J., E. Welch and J.P. Michaud. 1983. Control of internal phosphorus loading in a shallow lake by drawndown and alum. Proceedings of the Second Annual Conference of the North American Lake Management Society held on October 26-29, 1982 in Vancouver, B.C. EPA 440/5-83-001.

Jones, R.A. and G.F. Lee. 1977. Septic Tank Wastewater Disposal Systems as Phosphorus Sources for Surface Waters. Occasional Paper No. 13. Center for Environ,ental Studies, University of Texas at Dallas.

Kamp-Nielson, L. 1975. A kinetic approach to the aerobic sediment - water exchange of phosphorus in Lake Esrom. Ecological Modeling. 1: 153-160.

Kennedy, R.H. and G.D. Cooke. 1982. Control of Lake Phosphorus with Aluminum Sulfate: Dose Determination and Application Techniques. Water Resrouces Bulletin, 18(3): 389-395.

Kerfoot, W.B. and S.M. Skinner Jr. 1981. Septic leachate surveys for lakeside needs evaluation. Journal WPCF 53(12): 1717-1725.

Klopatek, J.M. 1978. Nutrient dynamics of freshwater riverine marshes and the role of emergent macrophytes. In, R.E. Good, D.F. Whigham, and R.L. Simpson (eds.), Freshwater Wetlands. Academic Press, New York.

Kluesener, J.W. 1972. Nutrient transport and transformation in Lake Wingra, Wisconsin. PhD. dissertation. Univ. of Wis., Madison.

Kumar, J. and J.A. Jedlicka. 1973. Selecting and installing synthetic pond linings. Chem. Eng. Feb. 5: 67-70.

Lake County Health Department. 1975-1982. Coliform bacteria counts for Cedar Lake. (unpubl.).

Lamarra, V.A. 1975. Digestive activities of carp as a major contributor to the nutrient loading of lakes. Verh. Int. Verein. Limnol. 19: 2461-2468.

Laude, E. 1977. Heavy metal pollution in Trondheim-sfjorden, Norway, and the recorded effects on the fauna and flora. Environ. Poll. 12: 187-198.

Lee, G.F. 1970. Factors affecting the transfer of material between water and sediments. Eutrophication Information Program, Literature Review No. 1, Univ. of Wisconsin, Madison.

Lee, G.F., W. Rast and R.A. Jones. 1978. Eutrophication of water bodies - insight for an age-old problem. ES & T. 12(8): 900-908.

Lindsey, A.A., D.V. Schmelz and S.A. Nichols. 1969. Natural Areas in Indiana and Their Preservation. Indiana Natural Areas Survey, LaFayette.

Loehr, R.C. 1974. Characteristics and comparative magnitudes of non-point sources. Journal WPCF. 46(8): 1849-1872.

Lorenzen, C.J. 1967. Determination of chlorophyll and pheo-pigments. Spectrophotometric equations. Limnol. Oceanogr. 12: 343-346.

Lucus, H.F., D.N. Edgington and P.J. Colby. 1970. Concentrations of trace elements in Great Lakes fishes. J. Fish. Res. Bd. Can. 27: 677-684.

Lynch, M. and J. Shapiro. 1979. Predation, enrichment, and phytoplankton community structure. Submitted to Limnology & Oceanography.

Manney, B.A. and R.G. Wetzel 1978. Seasonal changes in particulate and dissolved organic carbon and nitrogen in a hardwater stream. Arch. Hydrobiol. 80(1): 20-39.

Mathis, B.J. and T.F. Cummings. 1971. Distribution of selected metals in bottom sediments, water, clams, tubificid annelids and fishes of middle Illinois River. Report No. 41, University of Illinois Water Research Center, Champaign.

Mathis B.J. and N.R. Kevern. 1975. Distribution of mercury, cadmium, lead and thallium in a eutrophic lake. Hydrobiologia 46: 207-222.

Murphy, B.R., G.J. Atchison, A.W. McIntosh and D.J. Kolar. 1978. Cadmium and zinc content of fish from an industrially contaminated lake. J. Fish Biol. 13: 327-335.

Murphy, J., and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chem. Acta. 27: 31-36.

National Oceanic and Atmospheric Administration. 1971-1978. Climatological Date - Indiana Annual summaries, Vols. 76-83. U.S. Department of Commerce, Washington.

National Oceanic and Atmospheric Administration. 1979. Climatological data for the Lowell Indiana station. National Climatic Center, Ashville, N.C. (unpubl.)

Northwestern Indiana Regional Planning Commission. 1977. Growth Forecasting - A Phase in the Development of the Regional Plan. NIRPC, Highland, IN.

Odum, E.P. 1971. Fundamentals of Ecology. W.B. Saunders, Philadephia.

Omernik, J.M. 1976. The Influence of Land Use on Stream Nutrient Levels. U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis.

Otis, R.J. 1976. On-Site Disposal of Small Wastewater Flows. Small Scale Waste Management Project, University of Wisconsin-Madison.

Pecor, C.J., J.R. Novy, D.P. Tienney and S.L. VanLandingham. 1973. Water Quality of Houghton Lake. Technical Bulletin No. 73-7. Michigan Department of Natural Resources, Lansing.

Pecor, C.H., J.R. Novy, K.E. Childs and R.A. Powers. 1973. Houghton Lake Annual Nitrogen and Phosphorus Budgets. Technical Bulletin No. 73-6. Michigan Department of Natural Resources, Lansing.

Peters, G.O. Jr. 1982. Septic leachate detector research. Project 852-09. U.S. EPA, Environmental Impact Section, Chicago, IL

Peters, R.J. 1975. Phosphorus regeneration by natural populations of limnetic zooplankton. Verh. Int. Verein. Limnol. 19: 273-279.

Peterson, S.A., et al. 1974. Nutrient inactivation as a lake restoration procedure. Envir. Res. Lab, U.S. Environmental Protection Agency, Corvallis, Oregon.

Peterson S.A. 1979. Dredging and lake restoration. In, Lake Restoration. U.S. Environmental Protection Agency, U.S. Government Printing Office, Washington, D.C.

Peterson, S.A. 1981. Sediment Removal as a Lake Restoration Technique. EPA-600/3-81-013. U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis.

Petr, T. 1977. Bioturbation and exchange of chemicals in the mud-water interface. In, Golterman (ed.), Interactions between sediments and fresh water. Proceedings of an International Symposium held in Amsterdam, The Netherlands.

Pierce, N.D. 1970. Inland Lake Dredging Evaluation. Tech. Bull. No. 46. Wis. Dept. Nat. Res., Madison.

Prentiki, R.T., T.D. Gustafson and M.S. Adams. 1978. Nutrient movements in lakeshore marshes. In, R.E. Good, D.F. Whigham and R.L. Simpson (eds.), Freshwater Wetlands. Academic Press, New York.

Prescott, G.W. 1969. How to Know the Aquatic Plants. W.C. Brown and Co., Dubuque.

Prescott G.W. 1977. How to Know the Freshwater Algae. W.C. Brown and Co., Dubuque.

Preston, W.C. 1979. Measuring the effects of phosphorus on lake transparency and the fractional components of light attenuation. (unpubl.)

Prince, E.D., O.E. Maughan, and P. Brouha. 1977. How to Build a Freshwater Reef, Second Edition. Sea Grant at Virginia Tech, Extension Division, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Provasoli, L. 1969. Algal nutrition and eutrophication. In, National Academy of Sciences, Eutrophication: Causes, Consequences, Correctives. pp. 574-592.

Rast, W. and G.F. Lee. 1978. Summary Analysis of the North American (U.S. Portion) OECD Eutrophication Project: Nutrient Loading - Lake Response Relationships and Trophic State Indices. EPA-600/3-78-008. U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis.

Reckhow, K.H. 1978. Lake phosphorus budget sampling design. Paper presented at the America Water Resources Association Symposium on the Establishment of Water Quality Monitoring Programs.

Reckhow, K.H. 1979. Quantitative Techniques for the Assessment of Lake Quality. U.S. Environmental Protection Agency Report No. EPA-440/5-79-015. Washington.

Rhein, H.K., E.E. Stoops and W. Spaulding. 1978. Cedar Lake Park and Recreation Plan. Northwestern Indiana Regional Planning Commission, Highland, Indiana.

Rolfe, G.L., A. Haney and K. Rienbold. 1977. Environmental contamination by lead and other heavy metals, Vol II. University of Illinois, Urbana-Champaign.

Rolfe, G.L. and J.C. Jennet. 1973. Environmental lead distribution in relation to automobile and mine and smelter sources. In, Heavy Metals in the Aquatic Environment, P.A. Krenkel, (ed.), Pergamon Press.

Rosenshein, J.S. 1962. Geology of Pleistocene deposits of Lake County, Indiana. Geological Survey Research, Article 157. Indiana Department of Conservation, Indianapolis.

Stewart, W.P.D. 1969. Biological and ecological aspects of nitrogen fixation by free-living micro-organisms. Proc. Roy. Soc. London (ser. B), 172: 367-388.

Strickland, J.D. and T.R. Parsons. 1972. A Practical Handbook of Seawater Analysis. Fish. Res. Board Canada. Ottawa.

Sweeny, L.T. 1908. Biennial report of fisheries and game for Indiana. Indiana Department of Natural Resources, Indianapolis.

Syers, J.K., I.K. Iskandar and D.R. Keeney. 1973. Distribution and background levels in sediment cores from selected Wisconsin Lakes. Water Air Soil Poll. 2: 105-118.

Tarapchak, S.J. and E.F. Stoermer. 1976. Phytoplankton of Lake Michigan. Vol. 4: Environmental Status of the Lake Michigan Region. Argonne National Laboratory, Argonne.

Technicon Industrial Systems. 1977. Digestion and sample preparation for the analysis of total Kjeldahl nitrogen and total phosphorus in food and agricultural products using the Technicon BD-20 Block Digestor, industrial method No. 369-75A1B. Tarrytown, N.Y.

Tenney, M.W. and W.F. Echelberger, Jr. 1970. Flyash utilization in the treatment of polluted waters. Reprint from Bur. of Mines Inf. Circ. 8488. Ash Utility Proc. pp. 237-265.

Theis, T.L. 1979. Physical and chemical treatment of lake sediments. In, Lake Restoration. EPA 440/5-79-001. U.S. Environmental Protection Agency, Office of Water Planning and Standards. Washington, D.C.

Theis, T.L. and J.V. DePinto. 1976. Studies on the reclaimation of Stone Lake, Michigan. EPA-600/3-73-106. Ecol. Res. Ser., Washington.

Theis, T.L. and P.J. McCabe. 1978. Phosphorus dynamics in hypereutrophic lake sediments. Water Research 12: 677-685.

Theis, T.L. et al. 1979. Treatment of Lake Charles East, Indiana Sediments with Fly Ash. EPA-600/3-79-060. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis.

Torke, B.G. and W.H. Senft. 1979. A Classification and Management Plan for Indiana's Lakes. Final report for Public Lakes Assessment Contract submitted to the Indiana State Board of Health. Ball State University, Muncie.

U.S. Army Corps of Engineerings. 1976. Ecological Evaluation of Proposed Discharge of Dredged or Fill Material Into Navigable Waters. Misc. Paper D-76-17, Dredged Material Research Program. U.S. Army Engineer Waterways Experiment Station, Vicksburg.

U.S. Army Corps of Engineers. 1978. Guidelines for Designing, Operating, and Maintaining Dredged Material Containment Areas. Technical Report DS-78-10. Waterways Experiment Station, Vicksburg, Mississippi.

U.S. Department of Agriculture. 1972. Soil Survey of Lake County, Indiana. Soil Conservation Service, Washington, D.C.

U.S. Department of Health, Education and Welfare, Public Health Service. 1963. Memorandum report - Cedar Lake, Lake County, Indiana, Sanitation and Algae Problem. Report prepared by Great Lakes - Illinois River Basins Project. (unpubl.).

U.S. Environmental Protection Agency. 1973. Measures for the restoration and enhancement of quality of freshwater lakes. U.S. Government Printing Office, Wasington, D.C.

U.S. Environmental Protection Agency 1976a. Quality Criteria for Water. EPA-440/9-76-023. U.S. Environmental Protection Agency, Washington.

U.S. Environmental Protection Agency. 1976b. Report on Marsh Lake, Steuben County, Indiana. National Eutrophication Survey Working Paper NO. 333. Corvallis Env. Research Lab, Corvallis and Env. Monitoring and Support Lab, Las Vegas.

U.S. Environmental Protection Agency. 1976c. Report on Bass Lake, Starke County, Indiana. National Eutrophication Survey Working Paper No. 323. Corvallis Env. Research Lab, Corvallis and Env. Monitoring and Support Lab, Las Vegas.

U.S. Environmental Protection Agency. 1977. Guidelines for the pollutional classification of Great Lakes harbor sediments. U.S. EPA, Region V, Chicago (mineographed).

U.S. Environmental Protection Agency. 1979. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020. Environmental Monitoring and Support Lab, Cincinnati.

U.S. Environmental Protection Agency and WAPORA, Inc. 1979. Volume II - Draft Environmental Impact Statement, Alternative Wastewater Treatment Systems for Rural Lake Projects, Case Study Number 5: Otter Tail County Board of Commissioners, Otter Tail County, Minnesota. U.S. EPA Region V, Chicago, IL.

U.S. Geological Survey. 1974-1977. Gaging records from Cedar Lake station #5-5187.00. (unpubl.)

U.S. Geological Survey. Report on high stages and outlet conditions of Cedar Lake, Cedar Lake, Indiana (unpubl.)

Uttormark, P.D., J.D. Chapin and K.M. Green. 1974. Estimating nutrient loadings of lakes from non-point sources. EPA Ecological Research Series EPA-660/3-74-020. U.S. Environmental Protection Agency, Washington, D.C.

Uttormark, P.D. and M.L. Hutchins. 1978. Input/Output Models as Decision Criteria for Lake Restoration. Technical Report 78-03. Wisconsin Water Resources Center, Madison.

Vig, Reuben J. 1963. Geology of the Unconsolidated Deposits of Lake County, Indiana. Masters dissertation. University of North Dakota, Grand Forks.

Vollenweider, R.A. 1968. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Organization for Economic Cooperation and Development, Paris.

Vollenweider, R.A. 1975. Input-output models with special reference to the phosphorus loading concept in limnology. Schweiz. Z. Hydrol. 37(1): 53-84.

Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33: 53-83.

Weiler, R.R. 1973. The interstitial water composition in the sediments of the Great Lakes, I. Western Lake Ontario. Limnology and Oceanography, 18(6): 918-931.

Welch, E.B. 1979. Lake restoration by dilution. In, Lake Restoration. EPA 440/5-79-001. U.S. Environmental Protection Agency. Water Planning and Standards. Washington, D.C.

Welch, E.B., J.A. Buckley and R.M. Bush. 1972. Dilution as an algal bloom control. Water Pollut. Control Fed. 44(12): 2245-2265.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia.

Wetzel, R.G. and B.A. Manny. 1978. Postglacial rates of sedimentation, nutrient and fossil pigment deposition in a hardwater marl lake of Michigan. Pol. Arch. Hydrobiol. 25: 453-469.

Wilding, R.E. and R.L. Schmidt. 1973. Phosphorus release from lake sediments. Environmental Protection Agency. Ecol. Res. Ser. EPA-R3-73-024.

Yousef, Y.A., W.M. McLellon, H.H. Zebuth et al. 1978. Mixing effects due to boating activities in shallow waters. Technical report ESEI No. 78-10. Environmental Systems Engineering Institute, Florida Technological University.

Yousef, Y.A. W.M. McLellon and H.H. Zebuth. 1979. Changes in phosphorus concentrations due to mixing by motorboats in shallow lakes. Paper presented to the 1979 North American Lake Management Conference, East Lansing, Mich.

Zicker, E.L., K.C. Berger and A.D. Hasler. 1956. Phosphorus release from bog lake muds. Limnol. Oceanogr. 1: 296-303.

APPENDIX A - FIELD AND LABORATORY METHODS

WATER QUALITY METHODS

ALKALINITY

SAMPLE CONDITION - Stored at 5° C, less than 24 hours.

GENERAL METHOD Sample is titrated with N/44 sulfuric acid to a pH endpoint of 4.4. The reading on the burrette times 11.36 is the alkalinity as ppm of $CaCO_3$.

REFERENCE Frey, D.G. (personal communication). Biology Dept., Indiana University, Bloomington.

REAGENTS

A. 1N sodium carbonate.

Heat C.P. sodium carbonate in open crucible or evaporating dish to convert any bicarbonate to carbonate.

Cool and weigh out 5.302 g and dissolve in recently boiled deionized water, diluting up to 100 ml. This gives a 1N solution.

B. N/44 sulfuric acid.

To make a solution exactly N/44, make a 0.36N H_2SO_4 solution by diluting 10 ml conc H_2SO_4 to 1 liter in a volumetric flask with deionized water. Place 10 ml of 1N sodium carbonate in an erlenmeyer flask and add 5 drops of methyl orange. Titrate with 0.36N H_2SO_4 until color begins to change from yellow to red. If the acid was exactly 0.36N, then 27.78 ml of acid would be required to react with 10 ml of carbonate solution. Therefore, the number of ml of acid needed to make an exact N/44 solution is:

$$\frac{\text{av. ml titrated}}{27.78} \times 63.14$$

Dilute this quantity of 0.36N acid to 1 liter in a volumetric flask to give exactly N/44. Store in glass stoppered flask.

PROCEDURE

1. Transfer 100 ml of sample to a beaker.
2. Titrate with N/44 acid to a pH endpoint of 4.3-4.4, using a pH meter and probe.
3. Multiply reading on burrette by 11.36 to give alkalinity in ppm $CaCO_3$.

CONDUCTIVITY

SAMPLE CONDITIONS - Samples analyzed on site.

GENERAL METHOD Conductivity was measured with the HACH DR-EL/2 Field Kit with conductivity meter and temperature compensating probe.

CHLOROPHYLL a

SAMPLE CONDITIONS

- Stored at 5°C less than 48 hours.
- Unacidified and unfrozen.
- 2-3ml $MgCO_3$ added in field to liter samples
- Particulates collected on Whatman GF/C 4.25cm filters. Filters may be frozen and stored indefinitely.

GENERAL METHOD

Particulates collected on filter are ground in acetone. Plants pigments appear to be quantitatively extracted. The extract is filtered.

The filtered extract is read on the spectrophotometer in 1cm or 10cm cells, depending on concentration, at 665nm, 645nm, and 630 nm. Through a series of equations using known absorption coefficients, the concentration of Chl/a is determined.

Readings are corrected for pheophyton pigments by measuring the loss of absorption after acidification of the extract at 665 nm.

REFERENCES

Strickland, J.D., and T.R. Parsons. 1972. A practical handbook of seawater analysis. Fish. Res. Board Canada, Ottawa.

Lorenzen, C.J. 1967. Determination of chlorophyll and pheo-pigments. Spectrophotometric equations. Limnol. Oceanogr. 12: 343-346.

REAGENTS AND EQUIPMENT

A. Millipore filtration equipment to hold 4.25cm GF/C filters.

B. Low volume spectrophotometer cells having a pathlength of 10cm but a volume less than 10ml.

C. All glass filtration assembly to hold 2.4cm Whatman GF/C filters (See Fig. A) with 10ml graduated filtrate receiver.

D. Tissue grinder with Teflon pestle and metal shaft. May be used on 1/4" electric drill. Thomas grinder No. 4288-B is suitable.

E. Magnesium carbonate suspension

Add 1g finely powdered magnesium carbonate to 100ml deionized water. Shake before using.

F. 90% Acetone

Good quality, spectroanalyzed acetone should be used. 900 ml diluted to 1 liter volumetrically with deionized water.

PROCEDURE

1. Mix water sample well and measure an appropriate volume (V_1) into a graduated cylinder and collect particulate on a glass fiber filter. Vacuum should not exceed 15 inches of Hg.

2. If filters are not to be processed immediately, store in the dark at -10°C.

3. Place filter paper in tissue grinder with 2-3 ml of 90% acetone. Work in subdued light.

4. Grind for 1 minute taking care not to lose any of the solvent through splashing.

5. Transfer the paper and acetone slurry to an all-glass filtration assembly using 2-3 ml of 90% acetone to rinse out the tissue grinder. Collect acetone filtrate in a 10 ml graduated cylinder.

6. Wash the filter assembly with 2-3 ml of acetone.

7. Make the acetone extract up to 10 ml(or appropriate volume.).*

8. Zero spectrophotometer using 90% acetone blanks.

9. Measure extinction of extract at 750, 665, 645, and 630 nm. The measurement at 750 nm is used as a turbidity blank and is subtracted from the other readings.

10. To measure pheophyton pigments, add 2-3 drops of 50% HCl to sample. Invert the spectrophotometer cells several times to mix. Wait a few minutes and measure the extinction at 750 nm and 665 nm. The extinction at 750 nm is subtracted from the extinction at 665 nm.

CALCULATIONS

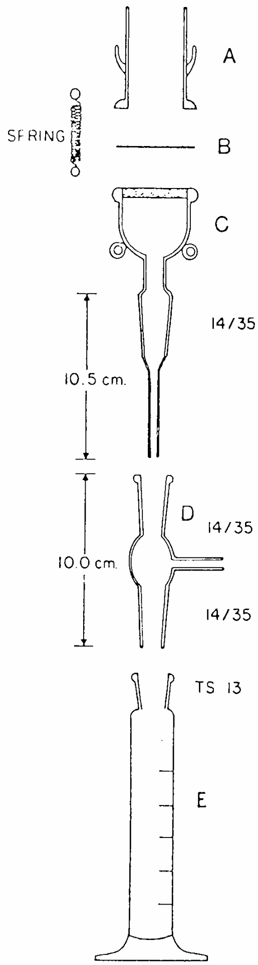
The corrected extinctions (750 nm subtracted) are entered into the following equations.

$$C = 11.6E_{665} - 1.31E_{645} - 0.14E_{630}$$

$$\text{Chl a, } {}^{mg}/m^3 = \frac{C \text{ x vol. of extract (ml)}}{\text{path length x vol. sample filtered (l)}}$$

* For example, if color of extract is very faint, may want to bring final extract volume up to a smaller volume, but greater than 5 ml.

ALL GLASS FILTRATION ASSEMBLY



(A) GLASS FUNNEL-50 ml.

(B) GLASS FIBER FILTER

(C) SINTERED GLASS FILTER SUPPORT WITH GROUND GLASS FITTING

(D) GLASS ADAPTER WITH SIDE ARM TO VACUUM AND GROUND GLASS FITTINGS

(E) 10 ml. GRADUATED CYLINDER

Figure A

To correct for pheophyton pigments, the concentration of pheophyton in $^{mg}/m^3$

$$\text{pheo, } {}^{mg}/m^3 = \frac{26.7\ (1.7\ [665_a] - 665_b) \times \text{vol. extract (ml)}}{\text{path length} \times \text{vol. sample filtered (l)}}$$

where 665_a is the extinction after acidification and 665_b is before.

This value is subtracted from the chl a value to give corrected chl a.

DISSOLVED OXYGEN (D.O.) AND TEMPERATURE

SAMPLE CONDITIONS - Samples analyzed on site.

GENERAL METHOD D.O. and temperature were measured with a YSI Model 54-A dissolved oxygen meter using a YSI Model 5 739 dissolved oxygen and temperature probe. The meter was calibrated on site by comparing against a Winkler D.O. Titration

pH

SAMPLE CONDITIONS - Samples analyzed on site.

GENERAL METHOD pH was measured with an Orion Ionalyzer pH meter and Corning portable pH electrode.

NITRATE AND AMMONIA

SAMPLE CONDITIONS
- Stored at 5° C.
- Acidified on site to pH2.

GENERAL METHOD
NO_3/NH_4 samples were first neutralized to pH 7-8 and analyzed on a Technicon Autoanalyzer II.

TOTAL KJELDAHL NITROGEN (TKN)

SAMPLE CONDITIONS

- Stored at 5°C.
- Acidified on site to pH 2.

GENERAL METHOD

Total kjeldahl nitrogen as used in this test is the sum of organic nitrogen and free ammonia. The test does not include compounds containing N-0 or N-N linkages.

A water sample is heated in the presence of conc. sulfuric acid, K_2SO_4 and $HgSO_4$ and evaporated until SO_3 fumes are obtained and the solution becomes colorless or pale yellow. The residue is cooled, and brought up to 250 ml with deionized H_2O. TKN is determined potentiometrically using an Orion ammonia probe.

The method is based on the fact that digestion with sulfuric acid and various catalysts destroys the organic material and nitrogen is converted to amonium acid sulfate. On making the reaction mixture alkaline ammonia is liberated and can be detected using an ammonia probe.

REFERENCE

EPA. 1979. Manual of methods for chemical analysis of water and wastes. Wash., D.C.

EQUIPMENT

A. Digestion apparatus: A Kjeldahl digestion apparatus with 100 ml flasks used under a fume hood to remove SO_3 fumes and water.

B. Orion digital selective ion meter and ammonia probe.

C. pH meter and pH probe.

REAGENTS

A. Distilled water should be free of ammonia. Such water is best prepared by the passage of distilled water through an ion exchange column containing a strongly acidic cation exchange resin mixed with a strongly basic anion exchange resin. Regeneration of the column should be carried out according to the manufacturer's instructions.

NOTE. All solutions must be made with ammonia-free water.

B. Mercuric sulfate solution: Dissolve 8 g red mercuric oxide (HgO) in 50 ml of 1:5 sulfuric acid (10.0 ml conc. H_2SO_4:40 ml distilled water) and dilute to 100 ml with distilled water.

C. Sulfuric acid-mercuric sulfate-potassium sulfate solution: Dissolve 267g K_2SO_4 in 1300 ml distilled water and 400 ml conc. H_2SO_4. Add 50 ml mercuric sulfate solution and dilute to 2 liters with distilled water.

D. Alkaline reagent.

Dissolve 40g reagent grade NaOH and 30g NaI in deionized water and dilute up to 100 ml.

E. Standard solutions - 20ppm as N

Dilute 2 ml 1000ppm stock N solution up to 100ml in a volumetric flask.

PROCEDURE

A. Micro-Kjeldahl digestion

1. Place 50 ml of sample in a 100 ml capacity kjeldahl flask.

2. Add 10 ml sulfuric acid-mercuric sulfate-potassium sulfate solution.

3. Evaporate mixture by heating until SO_3 fumes are given off and the solution turns colorless or pale yellow.

4. Digest for an additional 30 min.

5. Cool the mixture.

6. Transfer residue to a 250 ml volumetric flask, being sure to rinse the digestion flask thoroughly.

7. Dilute up to 250 ml.

B. Determination of ammonia in digested sample.

1. Place 97 ml of digested sample in a 250 ml Griffen beaker.

2. Add 3 ml alkaline reagent.
NOTE: The pH should be 12 or higher after alkaline solution is added.

3. Place ammonia electrode in solution. Turn meter to relative mV. Set readout to 000.0 with the calibration control.

4. While stirring with a magnetic stir bar, pipette 10 ml of the 20 ppm standard into the beaker. Record the meter reading when readout becomes stable.

CALCULATIONS

1. $C_s = Q \times C_r$

where C_s = concentration of NH_3 in the beaker of digested sample.

Q = concentration ratio (from table in instruction manual for Orion ammonia electrode).

C_r = standard concentration in mg/l NH_3.

2. Final concentration of lake sample is

$C_L = {}^{C_s}/_4 \times 20 = {}^{mg}/_l$ NH_3 in original lake sample.

3. To convert NH_3 to N

$C_L \times 0.85 = {}^{mg}/_l$ NH_3 - N, or TKN.

SOLUBLE REACTIVE PHOSPHORUS (SRP)

SAMPLE CONDITION

- Filtered through Whatman GF/C. stored at 5°C in acid rinsed Pyrex reagent bottles.
- Unacidified.
- Less than 24 hours old.
- Less than 5 ug AsO_4^{-3}/liter.

GENERAL METHOD

Phosphate, silicate, arsenate and germanate ions react under acidic conditions with molybdate to form heteropoly acids which can be converted, by suitable reducing agents, to blue compounds of uncertain composition.

Using appropriate acid and molybdate strength, ascorbic acid as reductant and antimony as a color enhancing species, an intensely blue colored complex is formed with PO_4^{-3} and AsO_4^{-3} having an absorbance maximum at 885 nm.

It should be noted that, while the formation of the blue complex is specific to PO_4^{-3}, some observers feel that the reaction conditions are capable of hydrolysing labile organic phosphorus compounds. This would give an overestimate of PO_4-P and hence an unreliable estimate of biologically available phosphorus.

REFERENCE

Murphy, J., and J.P. Riley. 1962. A modified single solution methods for the determination of phosphate in natural waters. Anal. Chim. Acta. 27:31-36.

REAGENTS

A. Acid molybdate-antimony

Distilled water	500 ml
Ammonium paramolybdate $(NH_4)_6Mo_7O_{24} \cdot 4\ H_2O$	7.5 g
Antimony potassium tartrate	0.14 g
Sulphuric acid (S.G. = 1.84)	88 ml

Mix in order given, cool and make to 1000 ml. Keep in dark glass bottle.

B. Ascorbic acid

Dissolve 2.5 g of L-ascorbic acid in 100 ml of distilled water. This reagent is stable for a few days if kept refrigerated.

C. Mixed molybdate for natural color determination

Mix 4 parts of reagent A. with 1 part of distilled water.

D. Mixed molybdate for orthophosphate determination

Mix 4 parts of Reagent A. with 1 part of Reagent B. Stable 1 day.

E. Phosphate standard

0.43925g KH_2PO_4 + 2.5 ml 20N H_2SO_4 brought up to 1 liter with deionized water. Add 2-3 drops chloroform, refrigerate. 1 ml of this stock solution contains 100 ug $P\text{-}PO_4$.

*Note: All glassware should be thoroughly washed with a PO_4 free detergent, soaked 1/2 hr in dilute (1:2) HCl, and rinsed ten times with tap water and ten times with deionized water.

PROCEDURE

1. Prepare standard solutions from stock PO_4 which bracket the expected sample concentrations.
2. Use a set of three test tubes for each sample, for each standard and for deionized water blank.
3. Place 25 ml of sample, standard, or deionized water into each test tube of its set.
4. To two tubes of each set, add 5 ml mixed molybdate reagent D.
5. To the remaining tube of each set add 5 ml molybdate reagent C, to be used as reagent/turbidity blank.
6. Allow color to develop for 5 min. and read on spectrophotometer at 885nm in appropriate 1 cm, or 10 cm cells.
7. Subtract sample blank extinctions from sample extinctions.
8. Subtract extinction of deionized water blank from standard extinctions. Plot the corrected extinctions of the standards and determine sample concentrations from the regression line through the standard points.

TOTAL PHOSPHORUS

SAMPLE CONDITIONS

- Stored at 5°C less than 7 days in acid rinsed Pyrex reagent bottles.
- Unfiltered, unacidified.

GENERAL METHOD

Digestion with acid and potassium persulfate releases phosphorus from organic material and phosphorus adsorbed to inorganic particles. Phosphate under acid conditions reacts with molybdate which, when reduced with ascorbic acid, forms blue compounds quantitatively proportional to the amount of phosphorus present. The blue compounds have an absorbance maximum at 885 nm.

It should be noted that molybdate also reacts with arsenates, which can affect the results. Pyrex glass should be used to help prevent this.

REFERENCE

Strickland, J.D., and T.R. Parsons. 1972. A practical handbook of seawater analysis. Fish. Res. Board Canada, Ottawa.

REAGENTS

A. 4N H_2SO_4

100 ml conc. H_2SO_4 diluted to 1 liter.

B. 10% potassium persulfate

10g potassium persulfate in 100 ml deionized water. Must be stirred and heated to go into solution.

C. Standard PO_4solution

0.43925g KH_2PO_4 + 2.5 ml 20N H_2SO_4 brought up to 1 liter with deionized water. Add 2-3 drops chloroform, refrigerate. 1 ml of this stock solution contains 100 ug PO_4-P.

D. Total P molybdate solution

25 ml conc. H_2SO_4 diluted to 1 liter. Add 9.6g NH_4 Molybdate + 0.2g potassium antimony tartrate. Must be stirred, not heated, for 12 hours to go into solution. Refrigerate in opaque (foil covered) Pyrex reagent bottle.

E. Ascorbic acid solution

2g ascorbic acid in 100 ml deionized water.

*Note: All glassware should be thoroughly washed with a PO_4 free detergent, soaked 1/2 hr. in dilute (1:2) HCl, and rinsed ten times with tap water and ten times with deionized water.

PROCEDURE

1. Prepare in duplicate 100 ml of phosphate standards having concentrations to bracket expected PO_4 levels in samples.

2. Mix samples well, do not filter.

3. Use three Kimax 9826 screw cap test tubes per sample, standards, and deionized water blank; two for duplicates, one for reagent/turbidity blank.

4. Add 50 ml of lake sample to each of three tubes. Add 50 ml standards and deionized water to each three of their own tubes.

5. Add 4ml 4N H_2SO_4 to all tubes. Heat 10% potassium persulfate solution to dissolve and add 4 ml of warm solution to all tubes. Cover tubes with aluminum foil and cap tightly to avoid boil over.

6. Autoclave for 2 hours on slow exhaust setting.

7. Allow to cool. May stand overnight.

8. Add 4 ml molybdate solution to each tube.

9. Add 2 ml deionized water to blank tubes only.

10. Add 2 ml ascorbic acid solution to remainder of tubes.

11. Cover tubes with Parafilm and invert to mix.

12. Allow color to develop for 15 min. and read on spectrophotometer at 885 nm using the appropriate 1cm, 4cm, or 10cm cell.

13. Plot corrected standard extinctions (standard extinction - deionized water blank extinction).

14. Determine sample concentrations using corrected sample extinctions (sample extinction - sample blank extinction) and the regression line through the standard points.

TURBIDITY

SAMPLE CONDITIONS - Stored at 5°C less than 24 hours.
- Unacidified.

GENERAL METHOD Turbidity was measured using the HACH Model 2100A Turbidimeter immediately upon return to the laboratory.

SEDIMENT CHEMISTRY METHODS

SEDIMENTS ELUTRIATE TEST

SAMPLE CONDITIONS

- Store immediately at 4°C. Do not freeze.
- Test as soon as possible, but within 1 week.
- Collect approx. 1 gal sediments, 1 gal sample water near bottom.
- Sediments stored in airtight whirl-pac bags, exclude air bubbles.
- Water samples stored in acid washed polyethylene bottles.

GENERAL METHOD

Filtered samples are analyzed for appropriate constituents before and after being agitated as a 1:4 mixture of sediment to water in order to determine release or uptake of that constituent.

REFERENCE

Modified from:

U.S. Army Corp of Engineers. 1976. Ecological evaluation of proposed discharge of dredged or fill materials into navigable waters. Wash., D.C.

EQUIPMENT

A. A. 2 stir plates with large Teflon stir bars.

B. 2 2000 ml Erlenmeyer flasks.

C. 1000 ml graduated cylinder.

D. Vacuum filter apparatus with 0.45 um membrane filters soaked in **dilute** HCl and rinsed before use.

E. Centrifuge capable of handling six 0.5 or 0.25 liter centrifuge bottles at up to 9000 RPM. Sorval Super Speed is appropriate with GSA rotor.

F. Air pump and water trap to supply oxygen to agitating samples.

PROCEDURE

1. Filter a portion of sample water, appropriate for the analysis of the constituent being looked at, through an acid-soaked 0.45um membrane filter prerinsed with 100 ml sample water. Discard rinse filtrate.

2. Analyze the filtered sample for constituent using appropriate method.

3. Mix well mixed sediment sample with unfiltered water sample in a 1:4 volumetric ratio, sediments to water. This is best done by placing 100 ml unfiltered water in a 1000 ml graduated cylinder. Sediment is added via a powder funnel to a total volume of 300 ml. (This gives 200 mls of sediment). This can be poured into one of the 2000 ml erlenmeyer flasks. Rinse the graduated cylinder with exactly 700 ml unfiltered sample water and pour into flask. This gives 200 mls sediment in 800 mls sample water (1:4).

4. Repeat 3 and place in second 2000 ml erlenmeyer for a duplicate.

5. Place flasks on stir plate and stir at fast speed for 30 min. In order to maintain oxygen level, air which has been first passed through a deionized water trap may be bubbled through the agitating sample mixture.

6. After agitating, allow mixture to settle 1 hour.

7. After settling, decant supernatant into centrifuge bottles and spin for 2 hours at 2500 RPM to remove bulk of suspended solids.

8. Decant this supernatant into new centrifuge bottles and spin at 9000-10,000 RPM for 2 hours. This will remove a good majority of fine suspended solids, such as clay.

9. Vacuum filter the supernatant through a 0.45 um membrane filter that has been soaked in acid and rinsed with 100 mls of centrifuged sample.

10. Analyze as soon as possible for constituents using appropriate analyses. Report averages of duplicates.

11. Results of before and after mixing can be compared to determine amount of release or absorption.

METALS IN SEDIMENTS

SAMPLE CONDITIONS

- Stored at 5° C.
- Samples are freeze dried and stored in desicators.

GENERAL METHOD

For analysis of cadmium, lead, iron, copper, and zinc, sediments are freeze dried and solubilized in nitric acid with a hot plate digestion.
Following digestion, sample is filtered. The filtrate is brought up to volume and can then be aspirated directly into the Atomic Absorption Spectrophotometer.

REFERENCES

Agemian, H. and A. Chau, Analytica Chimica Acta, 80 (1975) 61-66.
Standard Methods. APHA, (14th edition) pg. 169-170, pg. 151-152, pg. 144-162.
Methods for Chemical Analysis of Water & Waste (1972) EPA pg. 78-91.

EQUIPMENT

1. Atomic Absorption spectrophotometer
2. Hot plate digestion apparatus
3. pH meter
4. 100 ml Griffen digestion beakers
5. 100 ml volumetrics
6. Watch glasses
7. #40 Whatman filters
8. Funnel (glass)
9. Cathode Lamp(s)
10. 0.45 mm millipore filter
11. 125 ml linear polyethylene bottle
12. 200 ml volumetric

REAGENTS

A. Concentrated nitric acid

B. 1:1 HCl

C. Fisher stock standard metal solutions (1000 ppm).

D. Ammonium pyrrolidine dithiocarbamate (APDC)

   1. Dissolve 0.5 g of APDC in 500 ml of deionized H_2O.
   2. Filter through a 0.45 mm millipore filter.

E. Methyl isobutyl ketone (MIBK)

F. 0.3N HCl

1. Mix 25 ml concentrated HCl with deionized water and dilute to 1 liter.

G. 2.5 N Sodium Hydroxide

1. Dissolve 10 grams of NaOH in deionized H_2O and dilute to 100 ml.

PROCEDURE

Digestion

1. Weigh approx. 1.0 gram freeze-dried sample into a 100 ml Griffen beaker and record weight.

2. Leave one 100 ml Griffen beaker as a reagent blank, containing no sample.

3. Add 3 ml conc. HNO_3 to each beaker .

4. Place beakers on hot plate and digest to approximate dryness. This should be a gentle heating process which avoids a vigorous boil.

5. Remove the beakers from heat and add another 3 ml portion of HNO_3.

6. Place a watch glass on each beaker and return to heat. Each watch glass should fit so that vapors may escape, yet provide for refluxing.

7. Increase heat so gentle reflux occurs and continue heating. Add additional acid as necessary until digestion is complete (generally indicated by a light colored residue).

8. Add sufficient 1:1 HCl and warm the beakers to dissolve residue.

9. Wash down the beaker walls and watch glass with deionized water and filter the sample to remove silicates and other insoluble materials. Filter directly into a 100 ml volumetric.

10. Bring the sample up to 100 ml and immediately transfer solution to a linear polyethylene container.

11. The sample is now ready for Atomic Absorption Analysis.

NOTE * There are no significant interferences with this method.

Solvent Extraction

If the concentration of a particular metal is below detection, an extraction of metal chelates is required using MIBK in order to concentrate the metals. APDC is soluble in MIBK and can be extracted from the aqueous solution, carrying the chelated metals with it.

1. Transfer all of the sample to a 250 ml Griffen Beaker and adjust the volume to 100 ml with deionized water.

2. Prepare a blank and sufficient standards in the same manner and adjust the volume of each to 100 ml with deionized water.

3. Adjust the pH of the sample solution according to the following table for the element to be estracted with 0.3 N HCl solution, sodium hydroxide solution and pH meter.

Cd . . . . pH 1-6	Ni . . . . pH 2-4
Cu . . . . pH 1-8	Pb . . . . pH 2.5-3
Cr . . . . pH 6-8	Zn . . . . pH 2-6

4. Transfer sample and standard to a 200 ml volumetric and add 5 ml fresh 1% APDC solution and mix.

5. Add 10 ml of MIBK and shake 2 minutes; then allow phases to separate.

6. Aspirate the MIBK layer directly.

ATOMIC ABSORPTION INSTRUMENT PARAMETERS

Metal	Optimum Detection Range (mg/l)
Cadmium	0.05 - 2.0
Copper	0.2 -10.0
Iron	0.3 -10.0
Lead	1.0 -20.0
Zinc	0.05 - 2.0

NITROGEN AND PHOSPHORUS IN SEDIMENTS

SAMPLE CONDITIONS

-Core samples wrapped in plastic and aluminum foil and stored at 5° C.
-Samples can then be freeze dried and stored in a desicator.

GENERAL METHOD

Samples are digested with acid, potassium sulfate and mercuric oxide solution. They are then analyzed on the Technicon Autoanalyzer II. The heat is enough to volatilize all forms of N, but acid is strong enough to hold N in solution. Hydrogen peroxide is added to prevent organic acid from precipitating out. Phosphorus is determined by the phosphomolybdenum blue method on the autoanalyzer.

REFERENCE

Technicon Industrial Systems. 1977. Digestion and sample preparation for the analysis of total Kjeldahl nitrogen and total phosphorus in food and agricultural products using the Technicon BD-20 block digestor. Industrial method No. 369-75A/B. Tarrytown, N.Y.

REAGENTS AND EQUIPMENT

A. Digestion catalyst solution

Add 120 g K_2SO_4 and 0.35 g H_gO to 200 ml fresh H_2SO_4 (less than one week old). Heat to dissolve.

B. 50% H_2O_2

C. Block digester for holding 75 ml calibrated digestion tubes.

D. Hengar boiling chips.

PROCEDURE

1. Use 0.05, 0.1, or 0.2 g of dried sample, depending on per cent organic content (less than 20%, 20-50%, greater than 50%, respectively).

2. Weigh sample and place in dry digestion tube. It is a good idea to run duplicates. Also, leave one or two tubes empty for reagent blanks.

3. Add 5 ml catalyst solution to each tube.

4. Place 1 or 2 boiling chips in each tube.

5. Swirl tubes to mix.

6. Place tubes in preheated block (360°C) for 30 sec. Remove and wait one minute.

7. Add 2-3 mls. 50% H_2O_2.

8. Wait until bubbling subsides and replace tubes in block for 30 minutes. (Remove temporarily if foaming becomes heavy).

9. After digestion is complete, remove tubes from block and allow to cool for 10-15 minutes.

10. Add approximately 50 ml deionized water with vigorous agitation. A vortex type agitator is suitable.

11. Dilute to calibration mark.

12. Stopper tubes and invert three times to mix.

13. Allow to settle and cool to room temperature.

14. Analyze for N and P on Technicon Autoanalyzer II.

15. Concentrations of N and P are calculated as $^{ug}/g$ sample by:

$$\frac{\text{conc. after digestion, } ^{ug}/1 \times .075\ 1}{\text{weight of sample, g}} = {}^{ug}/g$$

% ORGANIC MATTER

SAMPLE CONDITIONS - Core samples were wrapped in plastic and aluminum foil and stored at 5°C.

GENERAL METHOD Samples are ashed at 550°C and 1000°C to drive off organic and inorganic carbon. The weight loss divided by the original dry weight gives % organic matter and % inorganic carbon.

REFERENCE Whitehead, D. (personal communication). Biology Dept., Indiana University, Bloomington.

EQUIPMENT

A. Muffle furnace

B. Balance capable of weighing out to 0.00001 g.

PROCEDURE

1. Take 1 cm^3 sediment and place in a pre-weighed porcelain crucible.
2. Dry in oven for 48 hours at 100° C.
3. Weigh sample to obtain dry weight.
4. Sample is then ashed at 550° C for 4 hours in a muffle furnace.
5. Sample is cooled in a desicator and weighed again. Loss of weight is due to loss of organic matter. Calculate per cent organic matter as

$$\%\ \text{org.} = \frac{\text{weight loss after ashing at 550°C.}}{\text{original dry weight}}$$

6. The sample is then ashed again at 1000° C. for 3 hours.
7. Cool sample in a desicator and weigh again. Weight loss is due to loss of inorganic carbon. Calculate per cent inorganic carbon as

$$\%\ \text{inorg.} = \frac{\text{weight loss after ashing at 1000° C.}}{\text{original dry weight}}$$

PARTICLE SIZE DISTRIBUTION OF SEDIMENTS

SAMPLE CONDITIONS - Core samples wrapped in plastic and aluminum foil and stored at 5° C.

GENERAL METHOD After digestion of organic matter, particles are washed to remove dissolved solids and resuspended in a solution of sodium metaphosphate. Subsamples are pulled at certain time intervals. Using Stoke's Law, particles of a certain size or smaller will remain in suspension a known period of time. The per cent of particles of one particular size class or smaller is determined by drying and weighing the pulls and comparing with the original dry sample weight.

REFERENCE Black, C.A. (ed.) 1965. Methods of soil analysis Part 1. Physical and mineralogical properties including statistics of measurement and sampling. American Society of Agronomy, Inc., Madison, Wisconsin.

REAGENTS AND EQUIPMENT

A. 30% H_2O_2

B. Sodium metaphosphate dispersing agent (Calgon).

Dissolve 50 g Calgon in deionized water.
Dilute to one liter.

C. Plunger for agitating mixture: This can be made by attaching a plastic disc, somewhat smaller than the inside diameter of a one liter graduated cylinder, to a wooden dowel long enough to reach the bottom of the cylinder.

D. Suction filtration apparatus: Using tubing with heavy walls, connect a Pasteur-Chamberland filter (fineness F) to a suction flask and to a pressure bulb through a 3-way stopcock. (Fig. 1). Connect the suction flash to a vacuum source.

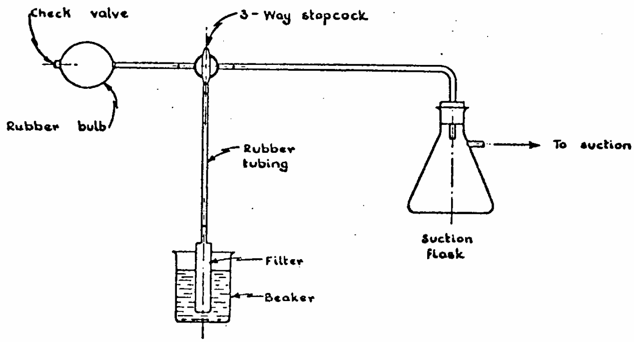
PROCEDURE

1. Place a subsample weighing approximately 10 g in a tared 250 ml beaker and weigh to the nearest 0.01 g.

2. Dry sample overnight at 105° C., cool in desicator and reweigh.

3. Add 30 ml deionized water, cover the beaker with a watch glass, and swirl to mix.

4. Add a few ml of 30% H_2O_2 and swirl if foaming occurs.



5. When reaction subsides, add additional H_2O_2 and complete digestion by heating for 1 hour or more at 90° C. on a hotplate. Repeat if it appears that digestion is not complete.

6. Remove excess liquid by filtering with the special filtration apparatus. When filter becomes coated, reverse stopcock and backwash by applying pressure with the rubber bulb.

7. After most of the water has been removed, add water and filter again.

8. Rinse filter and dry beaker and contents in oven at 105° C, cool in desicator.

9. Weigh the dry sample and beaker.

10. Place 10 ml of Calgon solution in a tared beaker and dry in an oven at 105° C. Cool and weigh. This amount of Calgon should be subtracted from all later evaporations.

11. Add 10 ml Calgon solution to sample beaker and swirl to mix.

12. Add deionized water to bring the volume up to 150 ml. and stir with a magnetic stirrer overnight.

13. Remove from stirrer and allow to settle.

14. Without shaking or swirling, pour the suspended portion into a 1 liter graduated cylinder.

15. Add more water, stir, and allow to settle 1-2 minutes. Pour into cylinder as before. Repeat until most of fine materials have been transferred.

16. Wash remainder of particles into the cylinder with a jet of water.

17. When the transfer is complete, add deionized water to bring the volume up to 1 liter.

18. Record temperature of suspension when it becomes constant.

19. Insert the plunger and move it up and down to mix the contents thoroughly. Avoid splashing.

20. When done mixing, record the time immediately.

21. Clamp a clean, dry 20 ml pipette in a holder so that the tip can be held exactly 10 cm below the surface of the suspension. Lower the pipette into the suspension 30 sec. before sampling.

22. Note the temperature and determine the sedimentation time required for desired particle size from Table 1.

23. At the chosen time, draw the sample into the pipette.

24. Run the suspension into a tared beaker. Rinse pipette and add washings to beaker.

25. Dry the sample in an oven at 105° C. for 12 hours, cool in a desicator and weigh the contents.

CALCULATIONS

Let w = dry weight of the pipette sample, v = volume of the pipette, and V = total volume of the suspension . Calculate the apparent (uncorrected) weight of particles in the given (cumulative) size range from the formula wV/v. Deduct the weight of dispersing agent per liter of suspension, using the data obtained by drying a 10-ml. sample of the 0.5N reagent. The result will be the cumulative weight ΣW. Determine by difference the weights W of the individual fractions.

APPENDIX B - 1979 and 1982 WATER QUALITY DATA FOR CEDAR LAKE AND ITS CONNECTED STREAMS

Cedar Lake Data Summary Sheet

Sample Date 3-2-79

Air Temperature (°C) 0
Cloud Conditions overcast/snow

Wind Speed 10-15 mph
Water Color Clear

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	0.7	3.2	3.5	1.3	3.1	3.8	2.0	3.1	3.7						
Dissolved Oxygen (ppm)	7.3	4.2	3.6	6.7	4.8	3.3	4.1	2.7	2.4						
D.O. % Saturation	51	31	27	46	36	25	29	20	18						
pH	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.5						
Alkalinity(ppm $CaCO_3$)	126	159	165	162	158	182	172	175	174						
Conductivity(μmhos-cm)	370	500	454	480	500	500	500	480	480						
SRP (μg/l)	---	---	84	---	99	CONTAM ---	INATION ---	133	113						
Total P (μg/l)	115	134	137	---	115	122	148	162	175						
Ammonia (mg/l)	1.17	.95	1.05	1.35	1.08	1.50	1.72	1.35	1.90						
Nitrate (mg/l)	2.56	1.09	.97	2.22	1.62	.89	1.48	.86	.74						
TKN (mg/l)	2.4	2.4	3.1	1.6	2.6	2.8	3.7	2.9	2.1						
Chlorophyll (mg/m^3)															
Turbidity (NTU)	1.1	1.2	1.7	1.1	1.0	1.3	1.1	1.1	1.2						
Secchi Depth (cm)															

Cedar Lake Data Summary Sheet

Sample Date 3-10-79

Air Temperature (°C) -8°
Cloud Conditions Clear/Flurries

Wind Speed 25 mph
Water Color Clear

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)															
Dissolved Oxygen (ppm)										5.8	5.0	11.0			
D.O. % Saturation										41	35	77			
pH										6.5	6.7	5.8			
Alkalinity(ppm $CaCO_3$)										3.3	4.7	6.2			
Conductivity(μmhos-cm)										161	256	294			
SRP (μg/l)										129.1	305.0	140.0			
Total P (μg/l)										198.0	390.4	210.1			
Ammonia (mg/l)															
Nitrate (mg/l)															
TKN (mg/l)										1.8	2.0	1.7			
Chlorophyll (mg/m^3)															
Turbidity (NTU)										6.6	7.0	12.0			
Secchi Depth (cm)															

Cedar Lake Data Summary Sheet

Sample Date 4-6-79

Air Temperature (°C) 1
Cloud Conditions Clear

Wind Speed 30 mph 60 mph previous day
Water Color Brown

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	4.9	4.8	4.8	4.8	4.6	4.6	5.0	4.5	4.1	5.8	5.5	5.5			
Dissolved Oxygen (ppm)	14.2	14.1	14.0	14.2	14.0	13.9	14.2	14.0	14.2	12.1	13.4	13.0			
D.O. % Saturation	110	110	109	110	108	107	111	108	108	97	106	103			
pH	8.1	8.0	8.0	8.0	8.0	8.0	8.2	8.0	8.0	7.5	7.4	7.7			
Alkalinity(ppm $CaCO_3$)	128	126	122	125	125	133	111	122	123	74	97	149			
Conductivity(μmhos-cm)	370	370	370	370	370	370	385	370	370	300	450	570			
SRP (μg/l)	<1	2	<1	1	<1	1	3	<1	2	60	---	---			
Total P (μg/l)	187	224	165	180	183	157	160	157	165	165	149	85			
Ammonia (mg/l)	---	.27	.29	.32	.27	.31	.34	.35	.33	.06	.21	.14			
Nitrate (mg/l)	---	.84	.83	.81	.80	.84	1.01	1.05	1.02	2.09	10.63	8.63			
TKN (mg/l)	2.5	2.9	2.4	2.9	3.0	2.9	1.7	2.3	2.3	2.0	1.4	.5			
Chlorophyll (mg/m^3)	71.6	44.9	39.5	42.0	34.5	45.7	40.0	39.0	40.7	0	15.6	0			
Turbidity (NTU)	11.0	14.5	15.7	14.0	15.6	16.3	13.3	15.3	15.6	19.6	12.0	4.3			
Secchi Depth (cm)	30			32			35								

Cedar Lake Data Summary Sheet

Sample Date 5-11-79

Air Temperature (°C) 22
Cloud Conditions 100%, light rain

Wind Speed Calm
Water Color Brown-Green

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	21.0	20.3	19.2	21.0	20.0	18.5	19.8	19.3	17.8	22.0	21.0	17.7	20.0	22.2	
Dissolved Oxygen (ppm)	13.2	11.8	9.7	13.1	11.4	6.7	12.4	11.2	8.2	3.1	1.0	7.3	11.4	7.4	
D.O. % Saturation	150	131	105	149	127	94	138	123	87	36	11	78	127	85	
pH	9.1	9.0	9.0	9.2	8.5	8.7	9.2	9.2	8.9	7.2	7.3	7.6	8.6	8.0	
Alkalinity(ppm $CaCO_3$)	110	110	106	108	108	109	109	102	108	115	134	144	109	107	
Conductivity(umhos-cm)	360	360	360	340	360	360	360	345	360	310	450	670	360	370	
SRP (µg/l)	5	6	6	6	11	10	5	6	10	58	132	90	7	9	
Total P (µg/l)	76	71	80	88	111	111	88	88	143	205	211	191	96	206	
Ammonia (mg/l)	0	.14	0	0	0	.03	.14	.03	.03	.11	.22	.14	0	.08	
Nitrate (mg/l)	.62	.70	.69	.64	.69	.76	.73	.84	.80	.03	.63	6.16	.73	.27	
TKN (mg/l)	2.2	2.0	2.2	2.7	1.9	2.5	2.4	2.1	2.2	2.3	2.3	1.8	2.3	2.0	
Chlorophyll (mg/m^3)	5.5	5.6	5.1	5.6	4.5	5.7	4.6	4.7	5.9	2.4	0.9	0.8	5.5	12.5	
Turbidity (NTU)	8.4	6.4	9.4	8.3	9.0	10.0	7.9	9.0	12.0	2.6	1.0	38.0	12.0	35.0	
Secchi Depth (cm)	58			59			58								

Cedar Lake Data Summary Sheet

Sample Date 5-25-79

Air Temperature (°C) 13
Cloud Conditions Clear

Wind Speed 20-30 mph
Water Color Brown

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	14.0	14.0	14.0	14.0	14.0	14.0	13.5	14.0	14.0	16.5	14.9	12.0	15.0	15.5	15.0
Dissolved Oxygen (ppm)	9.0	8.9	8.9	8.6	8.6	8.6	8.7	8.8	8.8	10.5	8.0	9.8	9.3	7.5	3.2
D.O. % Saturation	87	86	86	84	84	84	84	85	85	108	80	91	93	76	32
pH	8.4	8.3	8.4	8.4	8.3	8.1	8.5	8.4	8.2	8.9	7.5	7.5	8.5	7.2	7.1
Alkalinity(ppm $CaCO_3$)	128	118	118	119	118	119	119	117	118	116	168	193	120	115	202
Conductivity(µmhos-cm)	370	370	370	360	370	360	360	360	300	380	450	720	360	330	800
SRP (µg/l)	21	18	24	20	19	22	19	18	18	18	40	80	19	104	57
Total P (µg/l)	179	172	159	199	185	207	187	155	164	163	71	114	202	165	253
Ammonia (mg/l)	.34	.10	.20	.34	.20	.34	.10	.31	.27	.10	.10	.27	.17	.27	.66
Nitrate (mg/l)	.44	.43	.41	.42	.42	.45	.42	.42	.45	.40	.03	.84	.40	.03	.03
TKN (mg/l)	1.4	2.9	1.4	2.5	3.0	E.F.	1.0	1.0	3.1	3.1	1.5	1.3	3.6	1.8	2.1
Chlorophyll (mg/m^3)	61.5	72.0	102.2	84.6	79.3	80.3	70.5	83.4	79.9	67.7	2.3	4.2	100.4	0.0	25.7
Turbidity (NTU)	35	36	39	37	37	36	33	33	35	32	1.2	3.9	38	31	17
Secchi Depth (cm)															

(Too windy for Secchi reading)

Cedar Lake Data Summary Sheet

Sample Date 6-8-79

Air Temperature (°C) 29
Cloud Conditions 10%

Wind Speed 10-20 mph
Water Color Brown-Green

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	24.5	22.5	21.5	23.0	22.0	21.3	21.5	21.0	20.5	27.0	25.0	22.0	27.0	NO FLOW	NO FLOW
Dissolved Oxygen (ppm)	12.0	9.6	8.9	9.15	9.2	7.5	8.3	7.9	5.35	5.4	6.4	5.0	8.0		
D.O. % Saturation	145	112	102	108	106	85	95	90	61	68	78	57	101		
pH	7.35	8.15	8.20	8.5	8.2	8.35	7.25	8.20	8.20	7.0	7.7	7.7	7.7		
Alkalinity(ppm $CaCO_3$)	133	118	116	119	117	117	127	116	120	144	148	220	150		
Conductivity(μmhos-cm)	380	380	380	380	380	380	400	400	380	340	380	740	400		
SRP (μg/l)	11	13	13	19	17	20	23	22	24	71	118	367	42		
Total P (μg/l)	149	139	145	144	154	141	143	145	147	188	380	740	531		
Ammonia (mg/l)	.42	.42	.85	.28	0.0	.22	.20	1.35	1.70	1.10	.80	2.11	2.11		
Nitrate (mg/l)	.06	.06	.06	.07	.07	.09	.10	.10	.10	0.0	.05	.12	.07		
TKN (mg/l)	1.6	1.4	1.5	2.0	2.2	1.9	1.5	1.2	1.5	2.0	0.9	1.9	3.2		
Chlorophyll (mg/m^3)	51.8	32.6	64.6	50.2	45.4	58.5	40.7	43.1	35.7	-	-	-	-		
Turbidity (NTU)	14	16	16	16	15	16	15	15	13	10	11	28	37		
Secchi Depth (cm)	45			45			45								

Cedar Lake Data Summary Sheet

Sample Date 6-22-79

Air Temperature (°C) 24
Cloud Conditions 5%

Wind Speed 0-5 mph
Water Color Green

Parameters	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	23.5	23.0	22.5	24.0	23.0	22.5	24.0	23.7	22.5	24.8	26	21.8	Dry Bed	25.5	22.5
Dissolved Oxygen (ppm)	7.8	6.3	5.6	7.9	6.1	5.1	8.1	7.7	5.9	6.2	8.0	2.3		8.4	0.7
D.O. % Saturation	93	74	65	95	72	59	98	93	67	76	190	26		104	8
pH	8.0	7.8	7.5	8.1	7.6	7.5	8.0	7.7	7.5	9.25	8.4	7.2		9.5	7.2
Alkalinity (ppm $CaCO_3$)	127	125	126	119	124	122	122	120	120	107	123	108		124	242
Conductivity (μmhos-cm)	380	400	400	400	400	400	370	370	380	290	370	290		370	710
SRP (μg/l)	89	98	102	94	97	122	98	98	103	82	84	352		28	58
Total P (μg/l)	286	250	254	243	240	265	238	245	254	302	280	438		202	626
Ammonia (mg/l)	.48	.41	.52	.45	.48	.52	.38	.45	.62	1.01	1.08	.55		.76	.14
Nitrate (mg/l)	.08	.03	.04	.04	.04	.04	.04	.04	.04	.13	.10	.28		.08	.00
TKN (mg/l)	2.9	2.0	2.6	3.1	2.5	2.9	2.8	2.7	3.2	4.3	4.5	2.0		4.1	4.9
Chlorophyll (mg/m^3)	72.1	80.0	66.3	72.8	95.5	79.7	69.7	75.8	70.2	55.0	51.9	4.1		100.0	
Turbidity (NTU)	17	18	19	18	18	22	18	18	21	18	18	15		32	42
Secchi Depth (cm)	30			30			32								

Cedar Lake Data Summary Sheet

Sample Date 7-6-79

Air Temperature (°C) 25
Cloud Conditions 25%

Wind Speed 5-10 mph
Water Color Brown-Green

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	20.6	20.0	19.8	22.0	21.0	20.5	23.0	21.0	20.2	NO FLOW	25.0	Dry Bed	Dry Bed	NO FLOW	NO FLOW
Dissolved Oxygen (ppm)	9.7	8.3	7.1	10.4	8.3	7.6	12.4	9.4	8.9		10.0				
D.O. % Saturation	110	92	79	120	94	85	146	107	99		105				
pH	9.0	7.6	7.5	8.5	8.2	8.3	9.1	8.9	8.4		9.2				
Alkalinity(ppm $CaCO_3$)	128	134	131	128	131	133	131	131	132		133				
Conductivity(μmhos-cm)	370	370	370	370	370	370	400	380	380		400				
SRP (μg/l)	67	78	78	70	76	75	79	77	82		63				
Total P (μg/l)	255	276	294	260	264	294	260	280	293		225				
Ammonia (mg/l)															
Nitrate (mg/l)															
TKN (mg/l)	1.2	2.6	2.1	1.4	2.5	2.8	2.9	3.0	4.1		3.7				
Chlorophyll (mg/m^3)	98.0	131.4	125.5	108.1	128.0	137.7	126.0	126.0	143.7						
Turbidity (NTU)	16	17	16	15	16	17	16	16	18		17				
Secchi Depth (cm)	38			38			38								

Cedar Lake Data Summary Sheet

Sample Date 7-20-79

Air Temperature (°C) 29
Cloud Conditions 25%

Wind Speed 0-5 mph
Water Color Green-Brown

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	24.0	22.5	21.8	26.0	22.5	22.0	25.0	22.0	22.0	NO FLOW	25.9	Dry Bed	Dry Bed	20.5	NO FLOW
Dissolved Oxygen (ppm)	11.8	6.7	2.1	11.4	7.1	3.4	11.2	7.7	2.2		12.9			8.9	
D.O. % Saturation	142	78	24	143	83	39	137	86	25		161			100	
pH	8.9	8.7	8.2	9.0	8.7	7.9	9.0	8.7	7.0		8.9			7.7	
Alkalinity(ppm $CaCO_3$)	132	138	135	136	134	139	135	134	136		132			210	
Conductivity(μmhos-cm)	380	380	390	380	380	330	380	380	390		380			490	
SRP (μg/l)	90	102	108	90	103	116	100	100	114		79			17	
Total P (μg/l)	258	250	285	259	265	320	260	272	303		314			139	
Ammonia (mg/l)															
Nitrate (mg/l)															
TKN (mg/l)	3.3	2.2	2.5	1.6	2.2	2.3	2.5	2.7	3.4		3.0			2.5	
Chlorophyll (mg/m^3)	50.2	59.5	56.6	49.1	66.1	58.2	55.6	93.0	63.6						
Turbidity (NTU)	17	17	19	17	18	18	17	17	22		23			20	
Secchi Depth (cm)	27			32			29								

Cedar Lake Data Summary Sheet

Sample Date 8-3-79

Air Temperature (°C) 24
Cloud Conditions 90%

Wind Speed 10-15 mph
Water Color Brown-Green

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F Dry Bed	G Dry Bed	H NO FLOW	I NO FLOW
Temperature (°C)	25.2	24.9	24.0	25.5	24.8	24.5	24.8	24.0	21.4	23.5	25.5				
Dissolved Oxygen (ppm)	4.2	4.3	3.7	4.8	4.3	4.0	3.5	3.1	2.4	3.9	3.8				
D.O. % Saturation	51	52	46	59	52	48	43	37	27	46	47				
pH	7.7	7.7	7.8	7.6	7.5	7.7	7.4	7.4	7.4	7.8	7.7				
Alkalinity(ppm $CaCO_3$)	142	140	134	131	134	134	132	132	130	127	126				
Conductivity(µmhos-cm)	390	390	390	390	390	400	400	400	395	570	410				
SRP (µg/l)	178	176	183	190	185	177	195	177	192	279	130				
Total P (µg/l)	332	324	311	319	327	316	319	330	319	417	296				
Ammonia (mg/l)															
Nitrate (mg/l)															
TKN (mg/l)	3.6	3.2	3.2	3.2	3.2	3.2	3.4	3.1	3.0						
Chlorophyll (mg/m^3)	24.6	20.9	27.5	21.6	23.4	22.7	25.4	24.0	21.8						
Turbidity (NTU)	22	24	26	19	18	18	16	17	17	23	22				
Secchi Depth (cm)	28.5			31.0			32.5								

Cedar Lake Data Summary Sheet

Sample Date 8-16-79

Air Temperature (°C) 9:00 a.m. 18.5
Cloud Conditions 5%, Sunny 9:00 a.m.

Wind Speed Calm
Water Color Brownish-Green

Parameters	Sample Sites													
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	21.0	20.0	20.0	20.9	20.5	20.5	20.9	20.8	20.5		21.0			19.0	
Dissolved Oxygen (ppm)	7.5	6.28	5.0	6.75	6.50	6.55	6.65	6.80	6.60		9.0			4.7	
D.O. % Saturation	83	68	54	75	71	72	74	75	72		100			51	
pH	8.3	8.1	7.70	8.4	8.00	7.80	7.70	7.9	8.00		8.2			7.2	
Alkalinity(ppm $CaCO_3$)	13.4	13.4	13.4	13.3	13.3	13.3	13.3	13.3	13.2		13.2			13.6	
Conductivity(μmhos-cm)	410	410	410	410	410	400	425	420	410		375			410	
SRP (μg/l)	157	173	181	172	174	173	176	173	174		139			71	
Total P (μg/l)	361	335	394	332	335	337	348	320	342		668			305	
Ammonia (mg/l)	1.44	1.58	1.63	1.72	1.15	1.22	1.15	.97	.73		.82			.41	
Nitrate (mg/l)	.08	.03	.03	.04	.03	.03	.03	.04	.04		.10			.08	
TKN (mg/l)	4.17	4.96	4.96	4.42	4.48	4.48	5.31	3.06	3.25		6.2			2.89	
Chlorophyll (mg/m^3)	97.2	67.8	109	92	63	56	80	60	60						
Turbidity (NTU)	20	18	34	20	21	22	20	19	22		38			20	
Secchi Depth (cm)	28			28			28								

Cedar Lake Data Summary Sheet

Sample Date 8-31-79

Air Temperature (°C) 24.5°C
Cloud Conditions Clear 0%

Wind Speed slight breeze, 5-10
Water Color green

Parameters	Sample Sites													
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	24.5	24.2	22.8	24.0	23.5	22.3	23.9	23.3	23.0	20.3					
Dissolved Oxygen (ppm)	14.3	14.0	2.6	13.0	11.6	4.5	10.3	10.1	9.0	0.4					
D.O. % Saturation	168	119	30	153	135	51	121	116	103						
pH	9.3	9.3	9.1	8.6	8.7	8.6	8.4	8.4	8.4	6.6					
Alkalinity(ppm $CaCO_3$)	126	124	125	127	130	130	141	117	130	182					
Conductivity(µmhos-cm)	425	470	475	460	470	475	475	480	490	500					
SRP (µg/l)	74	78	77	80	89	101	103	97	100	102					
Total P (µg/l)	199	219	209	241	198	300	183	190	196	138					
Ammonia (mg/l)	5.46	5.04	17.23	4.20	1.40	2.66	1.96	3.22	2.66						
Nitrate (mg/l)	0	0	0	0	0	0	0	0	0						
TKN (mg/l)	3.44	2.86	3.39	3.15	2.00	3.47	2.46	2.47	2.50	1.98					
Chlorophyll (mg/m^3)	104	131	110	113	117	155	72	73	47						
Turbidity (NTU)	14	15	16	18	17	28	11	12	13	5					
Secchi Depth (cm)	40			40			45								

Cedar Lake Data Summary Sheet

Sample Date 9-14-79

Air Temperature (°C) 19
Cloud Conditions 50%

Wind Speed 15 mph
Water Color Green

Parameters	Sample Sites														
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D NO FLOW	E NO FLOW	F NO FLOW	G Dry Bed	H NO FLOW	I NO FLOW
Temperature (°C)	20.0	20.0	20.0	20.0	19.9	19.9	20.0	19.8	19.8						
Dissolved Oxygen (ppm)	7.4	7.3	7.3	7.7	7.5	7.4	7.7	7.2	7.2						
D.O. % Saturation	80	79	79	84	82	80	84	78	78						
pH	9.0	8.9	8.9	8.8	8.8	8.8	8.7	8.7	8.7						
Alkalinity(ppm $CaCO_3$)	128	130	128	128	130	131	134	128	130						
Conductivity(µmhos-cm)	390	390	390	395	395	395	395	395	395						
SRP (µg/l)	109	109	111	111	111	111	111	112	110						
Total P (µg/l)	277	257	260	283	281	272	263	260	258						
Ammonia (mg/l)	0.84	1.68	1.68	2.94	1.12	3.50	1.12	9.11	1.68						
Nitrate (mg/l)	0	0	0	0	0	0	0	0	0						
TKN (mg/l)	2.92	2.70	3.20	3.49	1.81	2.71	2.30	2.91	2.30						
Chlorophyll (mg/m^3)	92	94	83	68	93	92	84	83	86						
Turbidity (NTU)	27	25	26	28	27	27	23	24	23						
Secchi Depth (cm)	21.5			21.5			22								

Cedar Lake Data Summary Sheet

Sample Date 10-19-79

Air Temperature (°C) 17.5
Cloud Conditions Cloudy, 80%, light rain

Wind Speed 20-30 mph
Water Color brown-green

Parameters	Sample Sites													
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D	E	F	G	H	I
Temperature (°C)	12.0	11.5	11.5	11.9	11.3	11.3	11.9	11.7	11.7						
Dissolved Oxygen (ppm)	9.0	9.0	8.9	9.5	9.6	9.6	9.4	9.5	9.5						
D.O. % Saturation	83	82	81	88	87	87	87	89	89						
pH	8.5	8.7	8.8	8.3	8.5	8.6	8.4	8.4	8.5						
Alkalinity(ppm $CaCO_3$)	132	133	133	128	124	133	126	128	128						
Conductivity(μmhos-cm)	390	390	390	385	390	390	395	395	395						
SRP (μg/l)	154	153	154	154	153	160	160	159	154						
Total P (μg/l)	225	226	237	209	226	226	226	228	241						
Ammonia (mg/l)	1.82	1.12	1.12	1.26	1.12	.98	1.26	1.12	1.40						
Nitrate (mg/l)	0	0	0	0	0	0	0	0	0						
TKN (mg/l)	2.86	1.79	1.90	1.84	1.90	1.94	1.69	1.50	1.58						
Chlorophyll (mg/m^3)	37	21	32	26	21	18	18	18	21						
Turbidity (NTU)	20	19	21	18	17	18	17	17	17						
Secchi Depth (cm)	45			45			45								

Cedar Lake Project (Part 2) Data Summary Sheet

Sample Date April 21, 1982

Air Temperature 40°F

Wind Speed 5-10

Cloud Conditions clear

Water Color khaki

	SAMPLE SITE										
PARAMETER	C1	C2	C3	D	E	F	G	H	J	K	L
Temperature (°C)	12.0	11.5	11.0	8.9	10.2	10.0	10.5	10.0	10.1	13.0	10.0
Dissolved Oxygen (ppm)	11.6	11.0	10.6	4.2	10.2	12.9	10.7	7.7	8.5	9.6	11.0
pH	8.2	8.2	8.4	6.8	7.1	7.4	8.4	7.0	7.1	7.8	7.2
Total Solids (mg/l)	412	406	366	398	464	548	364	358	339	696	578
Volatile Total Solids (mg/l)	107	128	123	118	156	161	117	93	108	213	214
SRP (μ/l)	-	7.7	-	25.9	103.2	52.3	3.1	20.4	24.9	154.9	52.3
Total P (μ/l)	-	47	-	63	82	50	>200	142	92	39	40
Ammonia-N (mg/l)	-	0.03	-	0.07	0.03	-	0.03	0.09	0.14	0.01	-
TKN (mg/l)	-	4.30	-	-	6.88	3.30	5.26	4.28	5.26	>7.4	-
Secchi Depth (cm)	58										

Cedar Lake Project (Part 2) Data Summary Sheet

Sample Date May 20, 1982

Air Temperature $72^{\circ}F$

Wind Speed 9am 0 → 1pm 25-30

Cloud Conditions clear

Water Color khaki

PARAMETER	SAMPLE SITE C1	C2	C3	D	E	F	G	H	J	K	
Temperature (°C)	22.0	22.0	22.0	21.5	22.0	22.0	21.3	22.0	21.5	20.0	17.2
Dissolved Oxygen (ppm)	9.1	8.9	8.8	7.3	4.3	7.2	7.7	5.0	6.3	3.1	5.3
pH	8.1	-	-	7.2	6.9	6.9	7.9	7.0	6.7	7.2	7.2
Total Solids (mg/l)	448	485	532	440	613	629	544	663	558	633	721
Volatile Total Solids (mg/l)	142	168	174	172	217	173	175	206	230	226	250
SRP (μ/l)	-	9.5	-	70	275	157	9.5	9.5	355	-	195
Total P (μ/l)	-	95	-	134	245	133	63	448	461	317	149
Ammonia-N (mg/l)	-	0.12	-	0.43	0.49	0.29	0.01	0.05	0.19	2.89	0.39
TKN (mg/l)	-	0.79	-	1.64	0.31	0.55	0.31	1.03	1.50	2.12	1.26
Secchi Depth (cm)	52										

Cedar Lake Project (Part 2) Data Summary Sheet

Sample Date June 24, 1982

Air Temperature 68→ 75°F Wind Speed 0-5

Cloud Conditions slight haze Water Color Green

PARAMETER	SAMPLE SITE										
	C_1	C_2	C_3	D	E	F	G	H	J	K	
Temperature (°C)	21.0	21.0	20.7	19.7	17.5	NO	NO	18.6	17.0	18.0	NO
Dissolved Oxygen (ppm)	11.0	10.8	9.5	5.8	1.8	FLOW	FLOW	3.8	1.0	1.9	FLOW
pH	7.6	7.6	7.6	7.4	6.9			6.9	6.8	7.0	
Total Solids (mg/l)	429	438	435	602	520			522	280	715	
Volatile Total Solids (mg/l)	158	178	153	200	182			169	106	220	
SRP (μ/l)	-	8.1	-	49	93			11.5	495	172	
Total P (μ/l)	-	88	-	194	266			204	406	102	
Ammonia-N (mg/l)	0	1.4	-	1.4	2.7			1.2	2.9	7.5	
TKN (mg/l)	-	<1.0	-	<1.0	<1.0			3.3	<1.0	<1.0	
Secchi Depth (cm)	35										

Cedar Lake Project (Part 2) Data Summary Sheet

Sample Date 20 July 82

Air Temperature $75^{\circ}F$

Wind Speed 0-5

Cloud Conditions clear

Water Color green

PARAMETER	SAMPLE SITE C_1	C_2	C_3	D	E	F	G	H	J	K	L	
Temperature (°C)		26		25	NO	NO	NO	27	22	22	NO	
Dissolved Oxygen (ppm)		8.5		1.9	FLOW	FLOW	FLOW	0.9	0.5	0.6	FLOW	
pH		8.6		8.5				7.0	7.1	8.2		
Total Solids (mg/l)		-		-				-	-	-		
Volatile Total Solids (mg/l)		-		-				-	-	-		
SRP (μ/l)		80		80				28	900	421		
Total P (μ/l)		207		348				315	1947	933		
Ammonia-N (mg/l)		<0.1		<0.1				<0.1	4.5	<0.1		
TKN (mg/l)		1.7		2.3				0.9	5.0	0.1		
Secchi Depth (cm)		45										

APPENDIX C - ANALYSIS OF SYNTHETIC ORGANIC CHEMICALS IN CEDAR LAKE SEDIMENTS

SYNTHETIC ORGANICS IN CEDAR LAKE SEDIMENTS

To obtain a complete chemical characterization of the sediment in Cedar Lake, samples were analyzed for the presence of polychlorinated biphenyls. These ubiquitous and toxic compounds would constrain the disposal of dredge spoil if present in large concentrations. Furthermore the presence of PCB's in sediments would yield information valuable for other management decisions.

To this end, grab samples from the middle (coring site 1) and south basins (coring site 5) were taken during one of the summer sampling trips. These samples were kept in glass containers that were sealed with aluminum foil-lined lids. Samples were freeze-dried upon returning to the lab. Subsamples were then extracted in methylene chloride. This was followed by an acetonitrile partitioning clean-up procedure. The extract was subsequently analyzed by packed column gas chromatography.

Packed Column Gas Chromatography

Sample extracts were run with a spiked internal standard on the gas chromatograph (GC). Standard runs, using Aroclor type PCB's were also run using the spiked internal standard.

Both middle and south basin sample extracts showed an intense response from the electron capture detector. When sample retention times relative to the internal standard were compared to the Aroclor relative retention times, many of the sample peaks matched those of the PCB standard.

This initial information indicated that there may be some polychlorinated biphenyl in our sample extract. However GC retention times alone do not produce unequivocal identification of a compound in a complex matrix like lake sediment. Establishing the presence and quantity of a specific compound by gas chromatography requires extensive calibration against standards in a similar matrix and detailed extract clean-up procedures to eliminate formation of unresolved doublet peaks. This may become quite tedious and time consuming and may not be appropriate for the analysis of one or two samples.

One instrument which can provide reliable and specific structural information for complex environmental mixtures is the mass spectrometer. When used in connection with a GC, it is a valuable tool for environmental analysis. Thus, further investigations were directed toward analysis of the extract using a GC/MS/computer system.

GC/MS/COMP Analysis

A GC/MS/COMP system is well-suited for the identification of polychlorinated biphenyls for two reasons. First, the presence of chlorine will give a characteristic ^{35}Cl and ^{37}Cl isotope pattern in the spectra of a PCB compound. Second, PCB's will show major ion peaks at mass to charge ratios of 154 (biphenyl), 188 (mono-chlorinated biphenyl), and 222 (dichlorinated biphenyl). Selective ion monitoring may be employed to detect these mass to charge ratios. The spectra

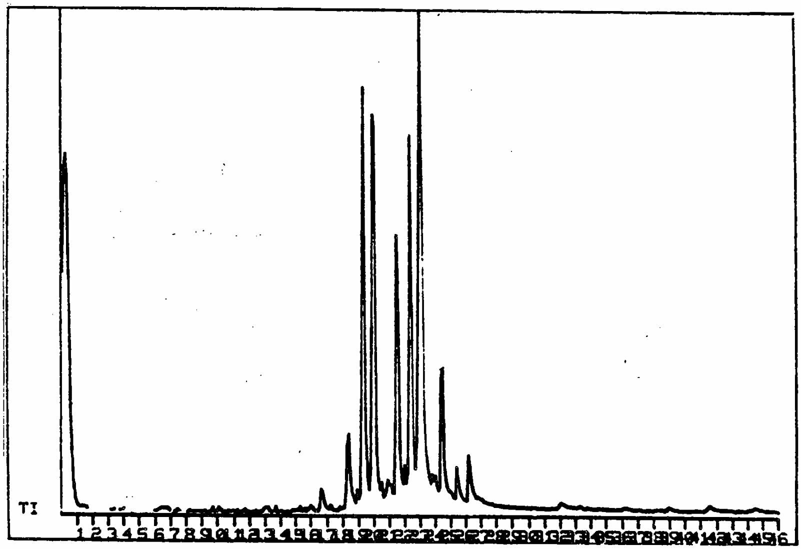


Figure C-2. Total ionization plot for GC/MS run of first chromatogram region of Cedar Lake sediment extract.

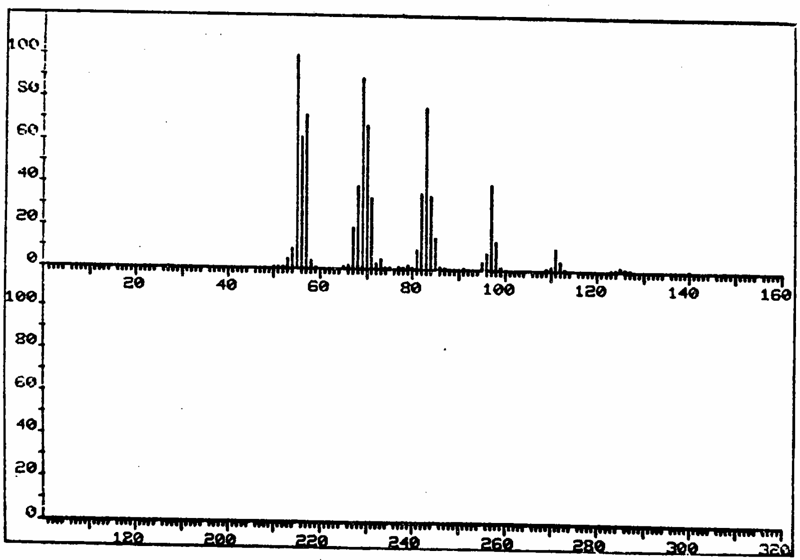


Figure C-3. Electron impact mass spectrum of a representative long chain alkene from first chromatogram region of extract from Cedar Lake sediment.

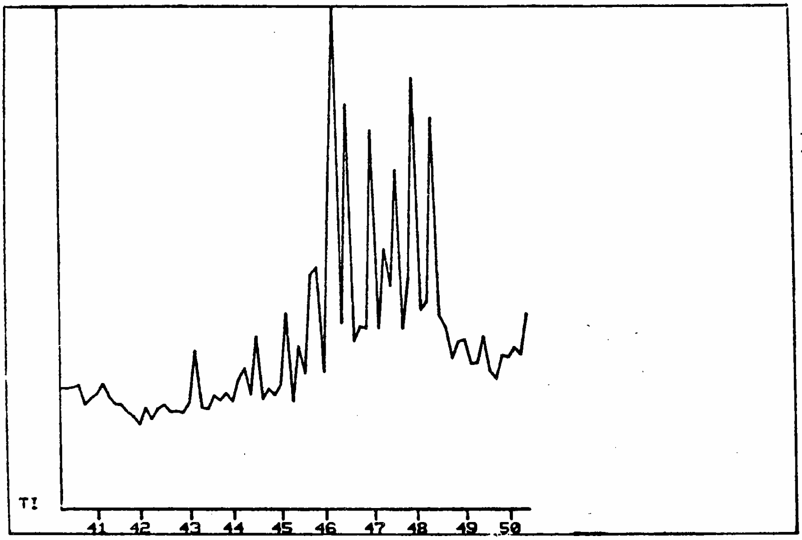


Figure C-4. Total ionization plot from second chromatogram region - of extract from Cedar Lake sediment.

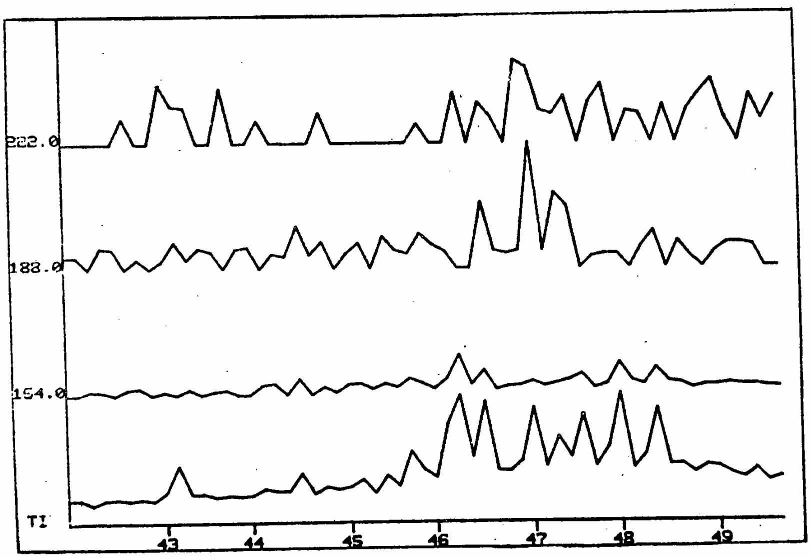


Figure C-5. Mass chromatograms from extract of Cedar Lake sediment for mass to charge ratios of 154, 188 and 222.

Cedar Lake

Lake County

Fish Management Report

Cedar Lake is a 781 acre natural lake located in Lake County in the extreme northwest corner of Indiana. Since the late 1940's, the lake has had a history of high bacterial counts and heavy algal blooms. Periodically the lake has been closed to swimming due to high bacterial counts.

The lake was originally surveyed in 1964 in an effort to provide fisheries information, along with a report by the U.S. Public Health Service and the Indiana Stream Pollution Control Board that would be useful in formulating future plans for the lake and surrounding area. The fish population in 1964 was found to be undesirable and the lake was renovated in the fall of 1966. Additional surveys were conducted in 1969, 1971, and 1974.

The present survey was conducted June 6-8, 1976. A total of 2,288 fish, representing 15 species was collected. Relative abundance by number of the major species was: gizzard shad 61.8%, carp 13.2%, goldfish 7.8%, bluegill 6.5%, black crappie 6.3%, channel catfish 1.8%, and largemouth bass 1.0%. Gizzard shad, carp, and goldfish made up 51.7% of the biomass. Bass, bluegill, black crappie, and channel catfish made up only 11.3% of the biomass. Other fish collected included both brown and black bullheads, northern pike, and walleye.

A total of 152 bluegill, ranging up to 6.5 inches in length, was collected. Both condition (relative plumpness) and growth of these fish were average, although less than 7% were of catchable size.

One hundred and forty-three black crappie were collected. Although growth of these fish was average, condition was below average. None was catchable size with the largest crappie collected measuring only 8.0 inches in length.

A total of 41 channel catfish was collected. These fish were not aged, however, there was good size distribution from 5.5 to 20.0 inches. All fish appeared plump and healthy.

Twenty-three largemouth bass, ranging in size from 4.5 inches to 15.0 inches in length, were collected. Growth and condition of these fish were average and over 17% of the bass were catchable size (14 inches or longer).

During the severe 1976-77 winter, low oxygen conditions were measured in Cedar Lake. Soon after ice out, dead fish began to appear on the shore. Although all species found in the 1976 survey seemed to have been affected, gizzard shad and channel catfish were most abundant of the dead fish observed. On June 9-10, 1977 a survey was conducted to determine what effect the winter kill had on the Cedar Lake fish population. Relative abundance by number of the six species collected in the 1977 survey was: black crappie 37.7%, carp 23.5%, bluegill 20.5%, goldfish 12.7%, pumpkinseed 3.4%, and largemouth bass 2.2%.

The winter kill appears to have significantly reduced or eliminated the gizzard shad and channel catfish populations. Seven other species collected in 1976 were not found in the 1977 sample. However, since these seven species accounted for only 1.6% of the 1976 sample, no conclusions as to how the winter kill affected them can be made. (See appendix for a complete list and size range of fish collected in 1977).

Although many of the local businesses and residences are now hooked up to the recently completed municipal sewage system, Cedar Lake remains a highly fertile body of water where dense algal blooms are common. High oxygen demand of bottom sediments contributed to the 1976-77 winter kill, and this condition may persist for some time despite the new sewage system.

Since the 1966 renovation, the fish population of Cedar Lake has been in a constant state of change. Bass, bluegill and crappie have failed to maintain populations that could be considered important to anglers. Rough fish expanded rapidly and continue to dominate the lake. The greatly enriched water that produces heavy algal blooms has detrimentally affected the fish. In clear lakes, FISHES

20. SPECIES AND RELATIVE ABUNDANCE BY NUMBER AND WEIGHT

COMMON NAME	SCIENTIFIC NAME	NUMBER	(%)	WEIGHT (LBS.)	(%)
Gizzard shad	Dorosoma cepedianum	1415	61.8	22.45	12.7
Carp	Cyprinus carpio	303	13.2	42.11	23.8
Goldfish	Carassius auratus	178	7.8	27.01	15.2
Bluegill	Lepomis macrochirus	149	6.5	3.09	1.7
Black crappie	Pomoxis nigromaculatus	143	6.3	2.62	1.5
Channel catfish	Ictalurus punctatus	41	1.8	45.26	25.5
Largemouth bass	Micropterus salmoides	23	1.0	9.71	5.5
Brown bullhead	Ictalurus nebulosus	10	*	3.02	1.7
Green sunfish	Lepomis cyanellus	8	*	.08	*
Longear sunfish	Lepomis megalotis	7	*	.24	*
Northern pike	Esox lucius	3	*	10.78	6.1
Pumpkinseed	Lepomis gibbosus	3	*	.13	*
Bowfin	Amia calva	2	*	8.83	5.0
Black bullhead	Ictalurus melas	2	*	.12	*
Walleye	Stizostedion vitreum	1	*	1.83	1.0

* Less than 1.0%

even when rough fish are present, their numbers are usually held in check, and they do not become dominant in the fishery. As the fertility of a lake increases, so does the turbidity of the water. The likelihood of plankton and filter feeding fish increasing in abundance becomes much greater.

Until the water quality of Cedar Lake improves and the dams below Lake Dalecarlia have been modified to prevent ingress of fish from Cedar Creek into Lake Dalecarlia, and eventually Cedar Lake, it is likely that rough fish will continue to dominate the fishery. The present dams at Lake Dalecarlia allow carp and shad to travel from Cedar Creek, over the dam, into Lake Dalecarlia. Since there is a connecting stream between Lake Dalecarlia and Cedar Lake, fish move from one lake to the other. Migrating rough fish have been observed entering Lake Dalecarlia over the dam, and entering Cedar Lake.

If improvements can be made in the dams and water quality, a second and more successful renovation should be considered. Until that time, the following is recommended:

1. The Department of Natural Resources should advise local residents how to modify the two dams at Lake Dalecarlia in order to prevent further rough fish contamination.

2. <u>All</u> local businesses and residences should immediately hook up to the municipal sewage system.

3. Channel catfish should be supplementally stocked into Cedar Lake.

4. If the above improvements are made and the fishery remains unsatisfactory, a total renovation should be considered provided that the water quality has improved sufficiently for bass and bluegill management.

Submitted by: Bob Robertson, Fisheries Biologist
Date: November 17, 1977

Approved by: Gary Hudson, Regional Fisheries Biologist
Date: December 30, 1977

Approved by: Bob Hollingsworth, Chief of Fisheries
Date: January 5, 1978

Fisheries Survey of Cedar Lake

Lake: Cedar
County:Lake

Date of Survey: August 20-21, 1979
Conducted by: Bob Robertson, Don Robertson, and members of I.U.'s Cedar Lake Project Staff.

1. Quadrangle name: Cedar Lake TWP .34N R .9W S22,23,26,27,34,35.

2. Nearest town: Crown Point.

3. Accessibility: state owned public access site.

4. Surface area: 781 acres maximum depth 16' average depth 9' acre ft. 6,749

5. Water level: 692.9 ft.

6. Location of benchmark: at spillway on Cedar Creek. elevation 695.83 MSL. Four other inlets are intermittent.

7. Outlet: Cedar Creek. location: east side.

8. Water level control: concrete dam with fixed crest.

9. Bottom type: primarily muck with some sand and gravel.

10. Watershed use: heavily residential with some commercial establishments. Some areas of marshland north and south of the lake, also some forests and farms.

11. Development of shoreline: heavily residential.

12. Previous surveys: 1964, 1969, 71, 74, 76, 77.

Sampling effort:

electrofishing	hours	1	total hours	2		
gillnets	number	2	hours	24	total hours	48
traps	number	2	hours	24	total hours	48
shoreline seining:	none					
rotenone:	none					

Biological Characteristics

Common species of aquatic plants and percent surface area covered.

Common name	Scientific name	Area of lake found in	depth found	percent covered
Spatterdock	*Nuphar advena*	along shorelines	0-3'	
Coontail	*Ceratophyllum demersum*	scattered	0-1'	minimal
Arrowhead	*Sagittaria latifolia*	scattered	0-3'	minimal
Algal bloom	largely *Microcystis*	extensive portions of lake	-	extensive

Comments Aquatic vegetation is limited primarily to scattered emergent plants because of turbidity.

Species and Relative Abundance

Common name	Scientific name	number	%	Wt.	%
carp	*Cyprinus caripio*	155	38.85	202.42	80.29
channel catfish	*Ictalurus punctatus*	38	9.52	13.54	5.37
black crappie	*Pomoxis nigromaculatus*	170	42.61	25.76	10.21
blue gill	*Lepomis macrahirus*	21	5.26	2.59	1.03
northern pike	*Esox lucuis*	4	1.00	4.75	1.88
black bullhead	*Ictalurus melas*	2	.50	.26	.10
largemouth bass	*Micropterus salmoides*	3	.75	.91	.36
orange-spotted sunfish	*Lepomis humilis*	4	1.00	.12	.04
goldfish	*Carassius uratus*	2	.50	1.76	.70
		399	100.00	252.11	100.00

APPENDIX E - SUMMARY OF PUBLIC MEETINGS HELD

A number of public meetins have been held between project personnel and the Cedar Lake public. All meetings were held in Cedar Lake following notices in the local newspaper, handbills, and other Town meetings. The following is a summary of those meetings.

May 10, 1979

This was an informational meeting to inform the Cedar Lake public of the goals and activities related to the project. Slides and overheads were used to present this material. Members of the public provided project personnel with:

a) information on the lake's history and where additional historical information could be found,

b) past efforts to improve the lake, including chemical treatments and groundwater dilutional pumping,

c) details related to the recently installed wastewater collection system, and

d) their concerns that springs in the lake had become silted in and that dredging was needed to open them up.

This information was investigated in subsequent months. Project personnel also got permission to enter private properties to carry on various project activities. Approximately 45 people attended this meeting which lasted 2 1/2 hours.

October 18, 1979

In this meeting, slides and overheads were used to inform the public of the results of Part One of the study. Restoration options related to dredging, nutrient inactivation, dilutional pumping, and do nothing were presented, along with preliminary costs and expected effectivenss of each option. No recommendations were made, at the request of the Indiana Department of Natural Resources, the sole funding agency at this time. The public was most concerned with the costs associated with dredging. The meeting was attended by representatives from the DNR; U.S. EPA; and local, state, and Federal elected officials. About 60 people attended this meeting which lasted 3 hours.

July 1982

This was another informational meeting, called at the request of local citizens, to inform the public about activities related to Part Two of the study. Citizens were interested in knowing why a second study was needed and were concerned about the availability of Phase 2 money. Approximately 40 people attended this meeting which lasted nearly 2 hours.

October 21, 1982

In this meeting results of Part Two of the study were presented to the public via slides and overheads. Restoration options detailed included dredging and biomanipulation. Dredging costs and time requirements were of concern of many people. The low costs associated with biomanipulation appealed to several people who spoke. Neither alternative was recommended as the "final plan" pending final results of phosphorus release from the sediment column test and additional discussions on biomanipulation options with members of the LASP team. Citizens raised additional concerns about the springs drying up, improvements to the lake's outlet structure, and the possibility of allocating state marine gasoline tax revenues to aid lake management efforts. The meeting was attended by representatives from the Indiana DNR; local, state, and Federal elected officials; and Dr. Byron Torke, Indiana's Clean Lakes Coordinator. Approximately 60 people attended the meeting which lasted 3 1/2 hours.

APPENDIX F - Public Opinion Questionnaire and Survey Results

At the first public meeting held in Cedar Lake on May 10, 1979, a questionnaire was passed out to the people in attendance with the purpose of finding out how people who live on or near Cedar Lake felt about a variety of issues regarding the restoration of the lake. The same questionnaire was later handed out on August 16, 1979, to people who were recreating at the lake. These lake users were sampled at the Pinecrest Marina and at the public landing. This section summarizes the results of the questionnaires and looks at differences in opinion of people who live on or near the lake and people from outside the area who use the lake.

A total of 60 questionnaires were returned, 44 from people attending the public meeting in May, and 16 from people who were using the lake on August 16, 1979.

Eighty percent of the people attending the public meeting said they lived on or near Cedar Lake. The people who responded that they did not live on Cedar Lake listed Dyer, Lowell, Crown Point, and Lemon Lake, all within a radius of about eight miles, as their place of residence.

Of the respondents who were out using the lake on August 16, eighty-eight percent said they did not live on Cedar Lake. Half of the respondents who did not live on Cedar Lake were from Illinois and had travelled between 11-24 miles to come to the lake.

Forty-three percent of the people who lived in the Cedar Lake area said they had lived there for more than twenty years. Fourteen percent said they had lived in the area for 10-20 years; fourteen percent lived in the area for 5-10 years; nine percent lived in the area for 1-5 yeras; and nine percent had lived in the area for less than one year.

These data indicate that the area is in a period of slow or moderate growth. The fact that the area is already heavily developed could be one reason.

Respondents who have lived in the lake area from 10-20 years and more than twenty years seem to be almost evenly divided as to whether the lake has improved, remained the same, or gotten worse. This could be due to respondents having difficulty deciding what time period to answer for, since the lake has gotten worse, remained the same, and improved all in the past twenty years or so. Respondents who indicated that they had lived in the area from 1-5 years were evenly divided between saying the lake had remained the same or improved. None of these respondents said that the lake had gotten worse. Respondents who had lived in the area for less than one year all indicated that they thought the lake had remained the same.

The lake uses which people enjoy most are the beauty of the lake, swimming, power boating, and fishing, in that order. Respondents attending the public meeting indicated the beauty of the lake (86%), fishing and swimming (66%) and power boating (52%) as the most enjoyed uses of the lake. The lake users indicated power boating (88%) and swimming (69%), as the most enjoyed uses. Beauty of the lake and fishing were indicated in just thirty-eight and twenty-five percent of responses, respectively. Water skiing was only mentioned by one user, but observations during sampling trips showed that it is a popular use.

Forty-one percent of the respondents from the public meeting indicated observing wildlife as one of the lake uses enjoyed. None of the lake users sampled indicated this activity.

Swimming (73%), fishing (62%), and the beauty of the lake (%) were indicated by all respondents as having been adversely affected by deteriorating quality of the lake. Swimming (77%), fishing and beauty of the lake (70%), and observing wildlife (57%) were indicated by all respondents as uses that would improve from the restoration project.

When asked to rank which problems were of most importance to Cedar Lake, the average of all respondents indicated that algae blooms were the worst problem, water clarity was second, lake filling by sediments was third, bad odors fourth, and fish kills fifth.

Public meeting respondents ranked problems in this order: 1) algae blooms, 2) lake filling by sediments, 3) water clarity, 4) bad odors, and 5) fish kills. Users ranked problems in this order, 1) water clarity, 2) algae blooms, 3) submerged aquatic weeds, 4) lake filling by sediments, and 5) bad odors and swimmers itch.

The fact that lake users felt that submerged aquatic weeds were a problem while public meeting attendees did not, may be expected from the fact that most users indicated power boating as a lake activity they enjoyed and submerged weeds can be a problem for power boats.

When asked to rank what they believed were the most important causes of lake problems, the average from all respondents indicated waste from septic tanks as the most important cause, lake sediments second, overuse of the lake from recreation third, farm runoff as fourth, and runoff from lawns and businesses on the lake as fifth.

Public meeting respondents ranked causes as follows: 1) lake sediments, 2) wastes from septic tanks, 3) overuse of the lake for recreation, 4) farm runoff, and 5) incoming streams. Users ranked them as follows; 1) waste from septic tanks and overuse for recreation, 2) runoff from lawns and business, 3) incoming streams, 4) industrial pollution, and 5) lake sediments.

It is interesting to note that lake sediments were ranked as the major cause by town meeting respondents but was ranked fifth by the user respondents. Several people at the meeting expressed strong conviction that lake sediments were the major cause because they were blocking springs that were believed to be present in the lake. It is also interesting to note that the user respondents ranked overuse from recreation as the major cause of problems for Cedar Lake.

Seventy-eight percent of all respondents indicated strong support for the restoration program and seventeen percent indicated support. Only two percent were neutral and none opposed the project. Of the town meeting respondents eighty-nine percent indicated strong support.

Seventy-two percent of all respondents indicated that they would support dredging as a technique for restoring Cedar Lake. This technique was indicated by eighty-four percent of the public meeting respondents, while only thirty-eight percent of the users indicated dredging. Most users (63%) indicated support for a lake water treatment and purification plant. Only twenty percent of public meeting respondents indicated support for this technique. Four (9%) of the town meeting respondents listed boat control under the "other" option.

In order to qualify for matching funds from EPA, more public access sites may be required on Cedar Lake. Respondents were asked whether they would give support to creating more public access sites on the lake. Fifty-two percent of the public meeting respondents indicated they would support this, while thirty-four percent indicated that they would not. Written comments from those opposing showed concern for increased boat traffic on the lake, which they thought was already heavy. Eighty-one percent of the users indicated that they would support the development of more public access sites on Cedar Lake.

Table F-1. Sample of questionnaire distributed at Cedar Lake.

INDIANA UNIVERSITY
School of Public and Environmental Affairs
Environmental Systems Application Center

QUESTIONNAIRE
CEDAR LAKE RESTORATION STUDY

The following questionnaire has been designed to acquire information about Cedar Lake. We have found that local residents are often an excellent source of information concerning specific problems on their lakes. Responses from local residents can be very useful in locating sources of pollution and in defining the exact nature of lake problems.

This questionnaire is also intended to provide you with an opportunity to express particular concerns and interests with regard to the restoration of Cedar Lake.

Take this opportunity to express your views. Please answer all questions. Thank you.

1. Do you live on Cedar Lake? a. yes b. no

   If not, where is your current place of residence? ____________________

2. How long have you lived in the Cedar Lake area?

   a. one year or less
   b. one to five years
   c. five to ten years
   d. ten to twenty years
   e. more than twenty years
   f. does not apply

3. Since you have been familiar with Cedar Lake, have you noticed that the condition of the lake has:

   a. improved b. remained about the same c. gotten worse

4. Which of the following lake uses do you enjoy?

   a. swimming
   b. power boating
   c. canoeing and/or sailing
   d. fishing
   e. diving
   f. observing wildlife
   g. beauty of lake itself
   h. others (list)
   ____
   ____

5. In your opinion which, if any, of the listed uses have been adversely affected by deterioration of the quality of your lake? Check the uses which you feel have been adversely affected.

a. swimming
b. power boating
c. canoeing and/or sailing
d. fishing
e. diving
f. observing wildlife
g. beauty of lake itself
h. others (list)
____
____

6. In your opinion which, if any, of the listed uses should be improved by this lake resotration project?

a. swimming
b. power boating
c. canoeing and/or sailing
d. fishing
e. diving
f. observing wildlife
g. beauty of lake itself
h. others (list)
____
____

7. The following list presents typical problems associated with recreational lakes. Rank on a scale from 1 to 5 those problems which <u>you consider</u> to be most important on Cedar Lake. If you feel that one of the items is not a problem, mark it with a zero.

1 2 3 4 5
not a problem worst problem

____ algae blooms
____ submerged aquatic weeds
____ fish kills
____ bad odors
____ swimmers itch
____ water clarity
____ lake filling by sediments

8. The following list presents typical causes of problems associated with polluted lakes. Rank on a scale from 1 to 5 those causes which <u>you consider</u> to be most important on Cedar Lake. If you feel that one of these items has not contributed to the lake's problems, mark it with a zero.

1 2 3 4 5
not a cause major cause

____ wastes from septic tanks
____ farm runoff
____ runoff from lawns and businesses on the lake
____ rainfall
____ industrial pollution
____ lake sediment
____ incoming streams
____ groundwater
____ overuse of the lake for recreation

9. Overall, how do you feel about the lake restoration program?

   a. strongly support
   b. support
   c. neutral -- neither support nor oppose
   d. oppose
   e. strongly oppose

   Comments:____

10. Which of the following restoration techniques would you support for restoring Cedar Lake?

   a. dredging
   b. nutrient inactivation with chemicals
   c. chemical treatment of algae
   d. weed harvesting
   e. land use regulations
   f. dilution of lake water with groundwater
   g. aeration and circulation
   h. lake water treatment and purification plant
   i. other ____________________________

11. In order to qualify for matching funds from the U. S. Environmental Protection Agency to restore Cedar Lake, more public access sites may be required on the lake. Given this, would you support or not support a proposal to provide more public access to Cedar Lake?

   a. support
   b. not support

   Comments:____

Table F-2. Summary of responses to the questionnaire distributed at a May 10, 1979 public meeting held in Cedar Lake and to users of the lake on August 16, 1979.

Question	Public Meeting #	Public Meeting %	Lake Users #	Lake Users %	Total #	Total %
1. Do you live on Cedar Lake?						
a. yes	35	80	2	12	37	62
b. no	9	20	14	88	23	38
					60	100
2. How long have you lived in the Cedar Lake area?						
a. one year or less	4	9	1	7	5	9
b. one to five years	4	9	1	7	5	9
c. five to ten years	8	18	0	0	8	14
d. ten to twenty years	8	18	0	0	8	14
e. more than twenty years	19	43	6	40	25	43
f. does not apply			7	47	7	12
					58	101
3. Since you have been familiar with Cedar Lake, have you noticed that the condition of the lake has:						
a. improved	13	30	5	33	18	31
b. remained about the same	17	39	9	60	26	44
c. gotten worse	14	32	1	7	15	25
					59	100
4. Which of the following lake uses do you enjoy?						
a. swimming	29	66	11	69	40	67
b. power boating	23	52	14	88	37	62
c. canoeing/sailing	14	32	3	19	17	28
d. fishing	29	66	4	25	33	55
e. diving	7	16	2	13	9	15
f. observing wildlife	18	41	0	0	18	30
g. beauty of lake itself	38	86	6	38	44	73
h. others	1	2	1	6	2	3
5. In your opinion, which if any of the listed uses have been adversely affected by deterioration of the quality of your lake?						
a. swimming	36	82	8	50	44	73
b. power boating	4	9	3	19	7	12
c. canoeing/sailing	6	14	0	0	6	10
d. fishing	33	75	4	25	37	62
e. diving	16	36	2	13	18	30
f. observing wildlife	10	23	1	6	11	18
g. beauty of lake itself	30	68	2	13	32	53
h. others (list)	3	7	0	0	3	5

Question	Public Meeting #	%	Lake Users #	%	Total #	%
6. In your opinion, which if any of the listed use should be improved by this lake restoration project?						
number of respondents	44	100	16	100	60	100
a. swimming	37	84	9	56	46	77
b. power boating	6	14	3	19	9	15
c. canoeing/sailing	14	32	0	0	14	23
d. fishing	37	84	6	38	42	70
e. diving	19	43	4	25	23	38
f. observing wildlife	29	66	5	31	34	57
g. beauty of lake itself	36	82	6	38	42	70
h. others (list)						

7. The following list presents typical problems associated with recreational lakes. Rank on a scale from 1 to 5 those problems which you consider to be most important on Cedar Lake.

1 2 3 4 5

not a problem worst problem

_algae blooms (algae)
_submerged aquatic weeds (weeds)
_fish kills (fish)
_bad odors (odors)
_swimmers itch (itch)
_water clarity (clarity)
_lake filling by sediments (filling)

Ranking	Public Meeting	Lake Users	Total
1.	algae	clarity	algae
2.	filling	algae	clarity
3.	clarity	weeds	filling
4.	odors	filling	odors
5.	fish	odors/itch	fish

8. The following list presents typical causes of problems associated with polluted lakes. Rank on a scale from 1 to 5 those causes which you consider to be most important on Cedar Lake.

1 2 3 4 5

not a cause major cause

_wastes from septic tanks (septic)
_farm runoff (farm)
_runoff from lawns and businesses on the lake (lawns)
_rainfall(rain)
_industrial pollution (industry)
_lake sediment (sediment)
_incoming streams (streams)
_groundwater (groundwater)
_overuse of the lake for recreation (overuse)

Ranking	Public Meeting	Lake Users	Total
1.	sediment	septic/overuse	septic
2.	septic	lawns	sediment
3.	overuse	streams	overuse
4.	farm	industry	farm
5.	streams	sediment	lawns

	Public Meeting #	%	Lake Users #	%	Total #	%
9. Overall, how strongly do you feel about the lake restoration program?						
a. strongly support	39	89	8	50	47	78
b. support	3	7	7	44	10	17
c. neutral	1	2	0	0	1	2
d. oppose	0	0	0	0	0	0
e. strongly oppose	0	0	0	0	0	0
					60	100
10. Which of the following restoration techniques would you support for restoring Cedar Lake?						
number of respondents	44	100	16	100	60	100
a. dredging	37	84	6	38	43	72
b. nutrient inactivation with chemicals	1	2	3	19	4	7
c. chemical treatment of algae	6	14	6	38	12	20
d. weed harvesting	5	11	5	31	10	17
e. land use regulation	9	20	2	13	11	18
f. dilution with groundwater	4	9	1	6	5	8
g. aeration and circulation	21	48	6	38	27	45
h. lake water treatment and purification plant	9	20	10	63	19	32
i. other (list)						
boat control	4	9	0	0	4	7
no opinion	2	5	0	0	2	3
11. In order to qualify for matching funds from the U.S. Environmental Protection Agency to restore Cedar Lake, more public access sites may be required on the lake. Given this, would you support or not support a proposal to provide more public access to Cedar Lake?						
a. support	23	52	13	81	36	60
b. not support	15	34	2	13	17	28
no opinion	6	14	1	6	7	12
					60	100

*Public meeting - 44 respondents; Lake users - 16 respondents

APPENDIX G - FINAL REGULATION ESTABLISHING OPERATING RULES AND PROCEDURES FOR THE CLEAN LAKES PROGRAM.

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Final Rule

Environmental Protection Agency

COOPERATIVE AGREEMENTS FOR PROTECTING AND RESTORING PUBLICLY OWNED FRESHWATER LAKES

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 35

[FRL 1388-4]

Cooperative Agreements for Protecting and Restoring Publicly Owned Freshwater Lakes

AGENCY: Environmental Protection Agency (EPA).

ACTION: Final rule.

SUMMARY: This regulation establishes policies and procedures by which States may enter into cooperative agreements to assist in carrying out approved methods and procedures for restoring publicly owned freshwater lakes, and protecting them against degradation, as authorized by section 314 of the Clean Water Act (33 U.S.C. 1251 *et seq.*). This regulation was proposed on January 29, 1979 (44 FR 5685) for a sixty-day public comment period. EPA received 48 letters of comment which we have considered in developing this regulation.

EFFECTIVE DATE: This regulation governs only clean lakes cooperative agreements which are awarded after February 5, 1980. Cooperative agreements and grants that are awarded before February 5, 1980, will continue according to their original terms subject to the regulations under which the funds were awarded. Clean lakes applications received before February 5, 1980 will be processed according to past procedures.

ADDRESSES: Comments submitted on these regulations may be inspected at the Public Information Reference Unit, EPA Headquarters, Room 2922, Waterside Mall, 401 M Street, SW., Washington, D.C. 20460, between 8 a.m. and 4 p.m. on business days.

FOR FURTHER INFORMATION CONTACT: Joseph A. Krivak, Criteria and Standards Division (WH-585), Environmental Protection Agency, Washington, D.C. 20460. Telephone: (202) 755-0100.

SUPPLEMENTARY INFORMATION: This regulation contains the policies and procedures governing the provision of Federal financial assistance to States for the protection and restoration of publicly owned freshwater lakes as authorized by the Clean Water Act (33 U.S.C. 1251 *et seq.*) Section 314. The program is called the clean lakes program.

The Federal Grant and Cooperative Agreement Act requires all Federal Agencies to classify each assistance transaction as either a grant or a cooperative agreement. EPA will award grants when little Federal involvement in the project is expected, and cooperative agreements when significant Federal involvement is anticipated. We expect significant EPA involvement in all Clean Lakes projects and have designated cooperative agreements as the appropriate award instrument.

Section 314 requires each State to prepare and submit a report to EPA including: (1) An identification and classification of all publicly owned freshwater lakes in that State according to eutrophic condition; (2) procedures, processes, and methods (including land use requirements) to control sources of pollution of these lakes; and (3) methods and procedures, in conjunction with appropriate Federal agencies, to restore the quality of these lakes. Section 314 also provides financial assistance to States to implement lake restoration and protection methods and procedures approved by the Administrator.

Pub. L. 95-217, amended section 314(b) of the Clean Water Act by adding the following: "The Administrator shall provide financial assistance to States to prepare the identification and classification surveys required in subsection (a)(1) of this section." On July 10, 1978, EPA published a notice of availability in the Federal Register for States to: identify and classify their publicly owned freshwater lakes according to trophic condition, establish priority rankings for lakes in need of restoration; and conduct diagnostic-feasibility studies to determine methods and procedures to protect or restore the quality of those lakes (43 FR 29617). Total assistance of up to $100,000 is available to each State for this lake classification survey. No award can exceed 70 percent of the eligible cost of the proposed project.

EPA carefully evaluated the performance of the clean lakes program during 1977 to determine how it might be improved. Based on this evaluation, we developed the revised procedures contained in this regulation. We published the proposed section 314 regulation, in the Federal Register (44 FR 5685) on January 29, 1979, for a sixty-day public comment period. In addition, we sent approximately 1000 copies of the proposed rule to the people identified on the current mailing list of the Environmental Resources Unit of the University of Wisconsin—Extension, to State agencies, environmental interest groups and specific requestors. The official comment period closed on March 30, 1979, and EPA has received 48 comment letters.

The following discussion responds to the comments received on the proposed regulation and is arranged in the order of the sections of the regulation. Changes made in the final form of the regulation in response to public comment are discussed. Our responses to significant comments that did not lead to changes are also discussed.

Definitions

Freshwater lake

Some commenters believed that the definition of freshwater lake (§ 35.1605-2) should not include a limiting value for total dissolved solids (TDS). Section 314 allows funding only for publicly owned "freshwater" lakes. Since TDS is found in various scientific texts as a measure to distinguish freshwater from brackish water and saltwater, we believe it is relevant. We have selected a value of 1 percent TDS which is ten times the value used on page 306 in the *Water Encyclopedia*, Water Information Center, Inc., Port Washington, New York, 1970. We used the high value so that freshwater lakes that have received a high TDS loading a result of irrigation return flows and other land management practices (primarily in the far West) can be eligible.

Publicly owned freshwater lake

Several comments concerned the definition of "publicly owned freshwater lake" (§ 35.1605-3). We proposed that a publicly owned freshwater lake is, "[a] freshwater lake that offers public access to the lake through publicly owned contiguous lands so that any member of the public may have the same or equivalent opportunity to enjoy privileges and benefits of the lake as any other member of the public or as any resident around the lake." We understand that a lakeshore property owner stands to receive greater benefit from a lake than a day visitor. We have omitted reference to the lakeside resident, but we are still concerned about the potential for the clean lakes program providing benefits to the lakeshore property owner rather than the general public. However, since projects demonstrating the greatest public benefits will receive the highest priority under the review criteria in § 35.1640-1, we do not expect problems.

Other commenters questioned the appropriateness of requiring publicly owned contiguous land as the public access point. We believe the requirement is necessary to ensure that the public maintains unrestricted use of a lake after it is improved. Even so, in some cases where publicly owned contiguous land is not available, the lake may have substantial public use and benefit. One State indicated that by State statute all lakes greater than 10 acres surface area are in the public domain even if the shoreline is totally private. The State statute also guarantees that public access will be provided. In these cases EPA will require the State to define exactly where the public access points are, and to provide written agreements between the State and particular private property owners specifying the conditions and limitations of the public access. We will also require permanent signs to show the public access points and specify any lake use limitations. Similarly, States could negotiate long terms leases or similar arrangements with private land owners, including private non-profits groups, to provide the necessary public access points. Again, we will require signs to indicate the limitations and extent of the public access. These arrangements would have to be completed before the award.

Eligibility

Some commenters suggested that section 314 cooperative agreements should continue to be awarded to local agencies. They contend that, otherwise, there will be a substantial erosion of the grassroots orientation of the program. We support the need to keep a grassroots thrust in the clean lakes program because of the voluntary nature of this assistance program. However, section 314 permits award of assistance only to States. Even so, since some States may not provide all the matching support required in clean lakes cooperative agreements, local agencies may provide the required remaining matching funds. We believe this funding partnership will preserve the grassroots nature of the program. We will work with the appropriate State agencies to assure that they minimize associated paperwork and "redtape," and provide clear concise guidance to local agencies. This will help to maintain the enthusiasm and involvement of local agencies.

EPA received several comments concerning the eligibility of Indian Tribes for section 314 funding. The commenters were concerned that, because Indian lands do not fall under the dominion of State Government, Tribal Governments may not be able to participate in this program. The statutory requirements of section 314 restricts award of assistance only to States. Section 35.1615 allows States to make financial arrangements with agencies located within the State including Indian Tribes to support lake restoration projects.

Some commenters objected to EPA's policy of not awarding assistance for lakes that are used only as drinking water supplies. EPA has operated under this policy since the first awards under the clean lakes program in January 1976. We believe that the primary purpose of section 314 is to implement the goals of the Clean Water Act stated in section 101(a) as they relate to publicly owned freshwater lakes. Section 101(a)(2) states that, "* * * it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for *recreation* in and on the water be achieved by July 1, 1983." (emphasis added) The conference committee report of the 95th Congress, first session (House Report No. 95–830) made special note on page 94 in the comments of changes made to the Clean Water Act by the 1977 Amendments, that EPA should give special attention to restoring lakes which offer the potential for high utility as recreation areas. In keeping with the existing EPA policy and in support of the Congressional intent, we do not believe it is appropriate to allow funding of projects for lakes that are used only as drinking water supplies. Other funding sources are available to assist municipalities and States with protecting or improving drinking water supplies. Most communities accomplish this by assessing an appropriate water users fee under a regular billing procedure to support reservior and processing plant operation and maintenance costs. Also, a portion of city and county taxes is likely to be used for such high priority community expenses.

Funding Levels

In the preamble of the proposed regulation, we requested comments on the proposed phasing of clean lakes cooperative agreements and the funding levels designated for each. The seventeen commenters who responded did not present persuasive arguments that the program would be more effective if the proposed matching requirements were reduced.

We continue to believe that the 50 percent matching requirement requires sufficient State/substate (non-Federal) commitment to assure the best project is implemented and proper maintenance of the project is continued after implementation is complete.

Lake Classification Requirement

A number of the comments concerned § 35.1630 requiring States to classify their publicly owned freshwater lakes in need of protection and restoration by January 1, 1982 in order to be eligible for funding support after that date under section 314. As explained in the preamble of the proposed rule, this requirement does not mean that all of a State's publicly owned freshwater lakes must be surveyed, but a State must provide EPA with survey results of their priority lakes and the rationale for selecting the lakes surveyed. Other comments concerned EPA financial assistance to the States to perform the lake classification requirement. EPA will continue to award this cooperative agreement to States on a one-time-basis, under the July 10, 1978, **Federal Register** notice, until September 30, 1981. Approximately 20 States applied for this funding assistance. Most projects will be conducted over 18 months. We will restrict funding of this activity to a one-time award until all States electing to participate have initiated these efforts, and we have reviewed the overall program results.

Monitoring

A few commenters suggested the EPA should make available a third award phase for intensive monitoring of perhaps 10 percent of the implementation projects. The projects would be carefully selected to evaluate those lake restorative techniques that have little documentation on their capabilities and effectiveness. Although committed to strengthen the understanding of procedures to protect and restore the quality of the Nation's lakes, we continue to believe that some monitoring of each project during and after project implementation will provide us with a better review of program effectiveness than intensive monitoring in a few projects. However, we are encouraging EPA's Office of Research and Development to conduct a greater number of intensive investigations of lake protection and restoration techniques under the 104(h) authority of the Clean Water Act. We believe this approach will be responsive to both the program needs and the intent of the legislation.

Application and Priority

Several commenters asked how many Phase 1 and Phase 2 project applications an individual State could submit for funding consideration. The regulation does not specify a number. However, all applications must receive a State priority and we will consider the State priority placed on an application along with the other criteria presented in § 35.1640–1 when developing funding recommendations. We do foresee instances where, after considering all of these factors, a State may receive more than one of each type of cooperative agreement.

A significant number of comments where received on the required content of Phase 1 project applications. Most of these comments indicated that the information required is excessive and costly to assemble or obtain. As discussed in the preamble of the proposed rule, we believe that this information should be readily available to States and local agencies. No study or water quality monitoring is necessary to obtain the information since only the presentation of existing information is required. Furthermore, the information required in Phase 1 applications is precisely the information that participating States are required to assemble under their lake classification surveys conducted under the July 10, 1978, **Federal Register** notice.

We have reduced the mandatory information required in Phase 1 applications in response to those comments. Although not mandatory, § 35.1620–2(b) still includes a list of information that EPA believes should be in a Phase 1 application to allow EPA to effectively evaluate project applications and make funding decisions. Applications describing a proposed project in more complete terms may receive higher rating when evaluated according to the review criteria in § 35.1640–1.

EPA received four comments on the State requirement to set priorities on Phase 1 and Phase 2 projects as stated in § 35.1620–5. The commenters were concerned principally with the State capability to foresee specific projects 12 to 18 months in advance in sufficient detail to allow them to apply realistic funding priorities. We understand the problems associated with these procedures and realized that projects and associated priorities set more than a year in advance are subject to change. In § 35.1620–5 we have allowed States to alter project priority lists with a minimum of State effort. We need the information contained on State priority lists to determine program needs. We also need it to provide a basis for adjusting our workforce to match the identified workload.

Allotment

In the preamble of the proposed regulation we request comments regarding the allocation of clean lakes program appropriations to assure an equitable distribution of funds among the States. We received 6 comments on this issue; 4 supporting the status quo, one supporting the specification in the regulation of an annual deadline for application submission, and the other suggesting that an allocation of appropriations be made directly to the

States, although no formula was proposed. EPA's Office of General Counsel (OGC) and Grants Administration Division (GAD) suggested that a Regional allocation formula be considered as a means of providing equitable funding distribution. Despite the relatively small amount of program appropriations, we believe an allocation procedure has considerable merit. The advantages include: Regional flexibility in the negotiations with States for lake restoration projects, and better Regional capability to forecast workloads and develop appropriate manpower plans for annual budget submissions. Considering the advantages mentioned above, EPA will provide each Regional office a resource target from the section 314 appropriation based on State's identification of clean lakes work in the State WQM work programs. The State identification will consist of a two year forecasting of clean lakes applications, with funding needs, as part of the annual work program. The summation of these forecasts, coupled with the Congressional appropriation, will permit EPA to provide equitable resource targets. Regional offices will use these targets to negotiate projects within each State.

Targetting, based upon two year forecasting in work programs, will take effect in fiscal year 1982. For fiscal year 1981, EPA will target resources based on State-supplied information in existing State/EPA agreements, WQM work programs, and from the WQM Needs Survey.

Review Criteria

We have changed the application review criteria presented under § 35.1640–1 to reflect several comments. We have added a criterion to emphasize the importance of improving fish and wildlife habitat, and improving the populations of fish species.

A few commenters questioned the applicability of application review criteria § 35.1640–1(a)(4)(ii–iv). We believe that these criteria should be considered by States to judge the cost of a project in relation to public benefits derived, e.g., the more persons using a restored or protected lake the greater the benefits from the expenditure of public funds. Further, persons with low incomes cannot travel easily to lakes for recreational purposes unless the lakes are close to have sufficient public transportation to them. Such factors should be considered in the decision making process. This component is not intended to preclude lakes in rural settings from receiving financial assistance under the clean lakes program.

The project award procedures under § 35.1650 have been changed. All EPA funding decisions will be made in the EPA Regional office by officials designated by the Regional Administrator. Program guidance and technical assistance will be supplied by EPA Headquarters, and all project applications will receive Headquarters review and technical recommendations.

Limitations on Award

Most comments on § 35.1650–2 were editorial and only minor changes in the language of this section have been made. Specific comments questioned the exclusion of aquatic plant harvesting as a lake restoration procedure. Section 35.1650–2(b)(5) does not exclude aquatic plant harvesting from supportable lake restoration programs. However, we believe that aquatic plant harvesting is only a temporary restorative measure in cases where pollution control measures are not implemented in the watershed to the greatest practicable extent. Even in cases where such pollution controls are in place, nutrient loading to the lake may be so great that harvesting aquatic vegetation may be required regularly to allow use of the lake. We will not generally consider a project for aquatic plant harvesting unless it will result in long lasting improvements.

A few commenters were confused regarding the relationship between 208 State and areawide wastewater management planning and the eligibility of a State to receive section 314 support. Section 208 planning does not have to be approved for a State to receive clean lakes assistance. If a 208 plan has been approved, the pertinent and applicable pollution controls identified in the 208 plan must be included in a clean lakes implementation plan. If a 208 plan has not been approved but has been developed, the pertinent and applicable pollution controls identified in the 208 plan should be included in the clean lakes project. If there is no 208 planning, then the lake protection and restoration procedures developed under a section 314 project should be consistent with 208 planning procedures so that the lake restoration planning can be included in any future 208 planning activities for the particular lake area.

In order to assure that these procedures are followed, States must certify under § 35.1620–2(a), that a project is consistent with the State Water Quality Management work program (see § 35.1513). Under § 35.1620–2(b), Phase 1 applications shall include written certification from the appropriate areawide or State 208 planning agency that work conducted under the proposed project will not duplicate work completed under any 208 planning grant, and that the applicant proposes to use any applicable approved 208 planning in the clean lakes project design. Under § 35.1620–2(c), Phase 2 applications must contain written certification from appropriate areawide or State 208 planning agencies that the proposed Phase 2 lake restoration proposal is consistent with any approved 208 planning.

One commenter suggested that 314 funding should be restricted so that it is not used to enhance boating or onshore recreational opportunities. EPA did not include these restrictions in the regulations for a variety of reasons. Lakes are traditionally used as recreational sites by the general public, and the degradation of those recreational sites through water pollution prompted the Congress to include section 314 in the Clean Water Act. EPA is supportive of the multiple use concept in the use of public funds. Frequently, the heavy use of the immediate lake shore will promote excessive pollutant loading, e.g., sediment and plant nutrients. In some cases, outright purchase of these lands to provide buffer strips is the most effective method of pollution control. Often lake shores can be used for low intensity recreational activities. Similarly, land abutting the lake may be purchased to provide an area to build a lake treatment structure and these areas should be considered for recreational opportunities.

Since recreational opportunities and water quality can sometimes be improved by removal of accumulated lake sediments, it would be inappropriate for EPA to ban dredging as an element of a comprehensive lake restoration project solely because it would benefit recreational activities.

As a means to assure that adverse environmental impact mitigation procedures are implemented in a lake restoration project, we have removed the 20 percent restriction on the cost of mitigation activities. All necessary mitigation activities should be included in the project. If mitigation costs are excessive, then the public benefits, when evaluated against project costs, will be lower and a proposed project will have lower priority for funding.

Conditions on Award

Numerous commenters were concerned about payment of the non-Federal share of a project by the State. We have modified § 35.1650–3(a)(2) to allow a State to arrange financing through substate financial agreements.

We understand that in many instances local agencies will be providing some or all of the required non-Federal matching share for clean lakes projects. It should be noted that as the only eligible award recipient, the State assumes the ultimate responsibility for the non-Federal share.

Some commenters argued that the monitoring program required under Appendix A (b)(3) is defined too rigidly. We agree, so we have modified the regulation to allow States and project officers to negotiate a program that is appropriate for each project.

Most commenters on the award conditions believe the requirement that States must maintain a project for ten years after a project is completed is excessive. We believe that States should agree to an operation and maintenance program that would assure that effective pollution controls are maintained to maximize the benefits in relation to the cost of the project. We believe that 10 years is a reasonable amount of time. Because we have no data to defend the cost effectiveness of this condition, it has been modified to cover only the project period. We believe the commitment by a State to an effective operation and maintenance program in the post project period is important and should be given special consideration in the evaluation of project proposals. Therefore, the evaluation criteria have been modified in § 35.1640–1 to include an assessment of the adequateness of the proposed post project operation and maintenance program.

We have changed section 35.1650–3(b) to allow Phase 1 recipients to negotiate with the project officer the project scope of work that is stated in section (a)(10) of Appendix A. Many commenters argued that the information required by section (a)(10) should be determined on a case by case basis. We believe that flexibility is desirable and will minimize project costs without sacrificing program integrity and public benefits. Similarly, we have modified § 35.1650–3(c) to allow flexibility on the design of Phase 2 monitoring programs to fulfill the requirement of section (b)(3) of Appendix A. Again, EPA project officer approval is required before the scope of work can be modified.

EPA received a significant number of comments on the reporting requirements in § 35.1650–5. The commenters were critical of the number of reports required and the amount of information required in Phase 1 project progress reports. Accordingly, we have modified the reporting requirements so that Phase 1 reports are only required semi-annually, and the final report will be the only Phase 1 report requiring the submission of water quality data. The frequency of Phase 2 reporting will not exceed quarterly and will be based on the complexity of the project. The reporting requirement will be stipulated in the cooperative agreement.

Several commenters requested clarification of subsection (e)(7) of Appendix A. We believe that recipients and EPA should have sufficient information about the usability of other lakes in proximity to the project lake to evaluate the benefits in relation to the costs of a proposed project. The funds available to support lake protection and restoration activities are limited. Information required by subsection (a)(7) should be helpful to States in establishing priorities for projects. The regulations do not require States to conduct exhaustive surveys of lake resources within a 80 kilometer radius of the project lake, but we do need an understanding of similar lake use opportunities in that distance to assure appropriate use of public funds.

A few comments concerned the procedures used to determine the limiting nutrient in lakes. Section (a)(10) of Appendix A requires the calculation of total nitrogen to total phosphorus ratios and/or the use of the algal assay bottle tests. One commenter stated that the algal assay bottle test should be a required procedure. Although the bottle test is an excellent investigative procedure, we believe that many States lack the appropriate equipment to perform these analyses and the costs would be excessive in some cases. Other commenters suggested that other forms of nitrogen and phosphorus should be used to calculate the N/P ratio. We are aware of the significant controversy over the appropriateness and reproducibility of tests using other fractional chemical forms of these nutrients. EPA believes that at this time, the total nitrogen and total phosphorus ratio is the most desirable test. Appendix A calls for the measurement of several chemical forms of these nutrients. Investigators and EPA may wish to calculate other ratios in addition to total nitrogen to total phosphorus using these measurements.

Since the publication of the proposed rules, EPA's Administrator on June 14, 1979, signed a memorandum to assure that all environmental measurements done with EPA funding result in usable data of known quality. Any clean lakes cooperative agreements, awarded after OMB approves the Administrator's directive under the Federal Reports Act will contain a condition requiring compliance.

State/EPA Agreement

In these and other regulations, we are developing the concept of a State/EPA Agreement. The Agreement will provide a way for EPA Regional Administrators and States to coordinate a variety of programs under the Clean Water Act, the Resource Conservation and Recovery Act, the Safe Drinking Water Act and other laws administered by EPA. This subpart governs only that part of the State/EPA Agreement which relates to cooperative agreements under the clean lakes program. Other programs included in the State/EPA Agreement will be governed by provisions found elsewhere in this chapter. Beginning in FY 1980, State programs funded under section 314 of the Act will be part of the State/EPA Agreement and the State/EPA Agreement must be completed before grant award. EPA will issue guidance concerning the development and the content of the State/EPA Agreement.

Regulatory Analysis

We have determined that this regulation does not require regulatory analysis under Executive Order 12044.

Evaluation

Section 2(d)(8) of Executive Order 12044 requires that each regulation be accompanied by a plan for evaluating a regulation after it issued. In order to comply with this requirement, EPA will conduct an evaluation of this regulation which will either be presented in the section 304(j) report, which is scheduled to be published in December 1981, or published separately.

Dated: January 28, 1980.

Douglas M. Costle,

Administrator.

PART 35, SUBPART H ADDED

EPA is amending Title 40 of the Code of Federal Regulations by adding a new Subpart H to Part 35 to read as follows:

PART 35—STATE AND LOCAL ASSISTANCE

* * * * *

Subpart H—Cooperative Agreements for Protecting and Restoring Publicly Owned Freshwater Lakes

Sec.

Authority: Secs. 314 and 501, Clean Water Act (86 Stat. 816; 33 U.S.C. 1251 *et seq.*)

Subpart H—Cooperative Agreements For Protecting and Restoring Publicly Owned Freshwater Lakes

§ 35.1600 Purpose.

This subpart supplements the EPA general grant regulations and procedures (Part 30 of this chapter) and establishes policies and procedures for cooperative agreements to assist States in carrying out approved methods and procedures for restoration (including protection against degradation) of publicly owned freshwater lakes.

§ 35.1603 Summary of clean lakes assistance program.

(a) Under section 314 of the Clean Water Act, EPA may provide financial assistance to States to implement methods and procedures to protect and restore publicly owned freshwater lakes. Although cooperative agreements may be awarded only to States, these regulations allow States, through substate agreements, to delegate some or all of the required work to substate agencies.

(b) Only projects that deal with publicly owned freshwater lakes are eligible for assistance. The State must have assigned a priority to restore the lake, and the State must certify that the lake project is consistent with the State Water Quality Management Plan (§ 35.1521) developed under the State/EPA Agreement. The State/EPA Agreement is a mechanism for EPA Regional Administrators and States to coordinate a variety of programs under the Clean Water Act, the Resource Conservation and Recovery Act, the Safe Drinking Water Act and other laws administered by EPA.

(c) These regulations provide for Phase 1 and 2 cooperative agreements. The purpose of a Phase 1 cooperative agreement is to allow a State to conduct a diagnostic-feasibility study to determine a lake's quality, evaluate possible solutions to existing pollution problems, and recommend a feasible program to restore or preserve the quality of the lake. A Phase 2 cooperative agreement is to be used for implementing recommended methods and procedures for controlling pollution entering the lake and restoring the lake. EPA award of Phase 1 assistance does not obligate EPA to award Phase 2 assistance for that project. Additionally, a Phase 1 award is not a prerequisite for receiving a Phase 2 award. However, a Phase 2 application for a proposed project that was not evaluated under a Phase 1 project shall contain the information required by Appendix A.

(d) EPA will evaluate all applications in accordance with the application review criteria of § 35.1640-1. The review criteria include technical feasibility, public benefit, reasonableness of proposed costs, environmental impact, and the State's priority ranking of the lake project.

(e) Before awarding funding assistance, the Regional Administrator shall determine that pollution control measures in the lake watershed authorized by section 201, included in an approved 208 plan, or required by section 402 of the Act are completed or are being implemented according to a schedule that is included in an approved plan or discharge permit. Clean lakes funds may not be used to control the discharge of pollutants from a point source where the cause of pollution can be alleviated through a municipal or industrial permit under section 402 of the Act or through the planning and construction of wastewater treatment facilities under section 201 of the Act.

§ 35.1605 Definitions.

The terms used in this subpart have the meanings defined in section 502 of the Act. In addition, the following terms shall have the meaning set forth below.

§ 35.1605-1 The Act.

The Clean Water Act, as amended (33 U.S.C. 1251 *et seq.*).

§ 35.1605-2 Freshwater lake.

Any inland pond, reservoir, impoundment, or other similar body of water that has recreational value, that exhibits no oceanic and tidal influences, and that has a total dissolved solids concentration of less than 1 percent.

§ 35.1605-3 Publicly owned freshwater lake.

A freshwater lake that offers public access to the lake through publicly owned contiguous land so that any person has the same opportunity to enjoy non-consumptive privileges and benefits of the lake as any other person. If user fees are charged for public use and access through State or substate operated facilities, the fees must be used for maintaining the public access and recreational facilities of this lake or other publicly owned freshwater lakes in the State, or for improving the quality of these lakes.

§ 35.1605-4 Nonpoint source.

Pollution sources which generally are not controlled by establishing effluent limitations under sections 301, 302, and 402 of the Act. Nonpoint source pollutants are not traceable to a discrete identifiable origin, but generally result from land runoff, precipitation, drainage, or seepage.

§ 35.1605-5 Eutrophic lake.

A lake that exhibits any of the following characteristics: (a) Excessive biomass accumulations of primary producers; (b) rapid organic and/or inorganic sedimentation and shallowing; or (c) seasonal and/or diurnal dissolved oxygen deficiencies that may cause obnoxious odors, fish kills, or a shift in the composition of aquatic fauna to less desirable forms.

§ 35.1605-6 Trophic condition.

A relative description of a lake's biological productivity based on the availability of plant nutrients. The range of trophic conditions is characterized by the terms of oligotrophic for the least biologically productive, to eutrophic for the most biologically productive.

§ 35.1605-7 Desalinization.

Any mechanical procedure or process where some or all of the salt is removed from lake water and the freshwater portion is returned to the lake.

§ 35.1605-8 Diagnostic-feasibility study.

A two part study to determine a lake's current condition and to develop possible methods for lake restoration and protection.

(a) The diagnostic portion of the study includes gathering information and data to determine the limnological, morphological, demographic, socio-economic, and other pertinent characteristics of the lake and its watershed. This information will provide recipients an understanding of the quality of the lake, specifying the location and loading characteristics of significant sources polluting the lake.

(b) The feasibility portion of the study includes: (1) Analyzing the diagnostic information to define methods and procedures for controlling the sources of pollution; (2) determining the most energy and cost efficient procedures to improve the quality of the lake for maximum public benefit; (3) developing a technical plan and milestone schedule for implementing pollution control measures and in-lake restoration procedures; and (4) if necessary, conducting pilot scale evaluations.

§ 35.1610 Eligibility.

EPA shall award cooperative agreements for restoring publicly owned freshwater lakes only to the State agency designated by the State's Chief Executive. The award will be for projects which meet the requirements of this subchapter.

§ 35.1613 Distribution of funds.

(a) For each fiscal year EPA will notify each Regional Administrator of the amount of funds targeted for each Region through annual clean lakes program guidance. To assure an equitable distribution of funds the targeted amounts will be based on the clean lakes program which States identify in their State WQM work programs.

(b) EPA may set aside up to twenty percent of the annual appropriations for Phase 1 projects.

§ 35.1615 Substate agreements.

States may make financial assistance available to substate agencies by means of a written interagency agreement transferring project funds from the State to those agencies. The agreement shall be developed, administered and approved in accordance with the provisions of 40 CFR 33.240 (Intergovernmental agreements). A State may enter into an agreement with a substate agency to perform all or a portion of the work under a clean lakes cooperative agreement. Recipients shall submit copies of all interagency agreements to the Regional Administrator. If the sum involved exceeds $100,000, the agreement shall be approved by the Regional Administrator before funds are released by the State to the substate agency. The agreement shall incorporate by reference the provisions of this subchapter. The agreement shall specify outputs, milestone schedule, and the budget required to perform the associated work in the same manner as the cooperative agreement between the State and EPA.

§ 35.1620 Application requirements.

(a) EPA will process applications in accordance with Subpart B of Part 30 of this subchapter. Applicants for assistance under the clean lakes program shall submit EPA form 5700-33 (original with signature and two copies) to the appropriate EPA Regional Office (see 40 CFR 30.130).

(b) Before applying for assistance, applicants should contact the appropriate Regional Administrator to determine EPA's current funding capability.

§ 35.1620-1 Types of assistance.

EPA will provide assistance in two phases in the clean lakes program.

(a) *Phase 1—Diagnostic-feasibility studies.* Phase 1 awards of up to $100,000 per award (requiring a 30 percent non-Federal share) are available to support diagnostic-feasibility studies (see Appendix A).

(b) *Phase 2—Implementation.* Phase 2 awards (requiring a 50 percent non-Federal share) are available to support the implementation of pollution control and/or in-lake restoration methods and procedures including final engineering design.

§ 35.1620-2 Contents of applications.

(a) All applications shall contain a written State certification that the project is consistent with State Water Quality Management work program (see § 35.1513 of this subchapter) and the State Comprehensive Outdoor Recreation Plan (if completed). Additionally, the State shall indicate the priority ranking for the particular project (see § 35.1620-5).

(b) Phase 1 applications shall contain: (1) A narrative statement describing the specific procedures that will be used by the recipient to conduct the diagnostic-feasibility study including a description of the public participation to be involved (see § 25.11 of this chapter);

(2) A milestone schedule;

(3) An itemized cost estimate including a justification for these costs;

(4) A written certification from the appropriate areawide or State 208 planning agency that the proposed work will not duplicate work completed under any 208 planning grant, and that the applicant is proposing to use any applicable approved 208 planning in the clean lakes project design; and

(5) For each lake being investigated, the information under subparagraph (5)(i) of this paragraph and, when available, the information under subparagraph (5)(ii) of this paragraph.

(i) Mandatory information.

(A) The legal name of the lake, reservoir, or pond.

(B) The location of the lake within the State, including the latitude and longitude, in degrees, minutes, and seconds of the approximate center of the lake.

(C) A description of the physical characteristics of the lake, including its maximum depth (in meters); its mean depth (in meters); its surface area (in hectares); its volume (in cubic meters); the presence or absence of stratified conditions; and major hydrologic inflows and outflows.

(D) A summary of available chemical and biological data demonstrating the past trends and current water quality of the lake.

(E) A description of the type and amount of public access to the lake, and the public benefits that would be derived by implementing pollution control and lake restoration procedures.

(F) A description of any recreational uses of the lake that are impaired due to degraded water quality. Indicate the cause of the impairment, such as algae, vascular aquatic plants, sediments, or other pollutants.

(G) A description of the local interests and fiscal resources committed to restoring the lake.

(H) A description of the proposed monitoring program to provide the information required in Appendix A paragraph (a)(10) of this section.

(ii) Discretionary information. States should submit this information when available to assist EPA in reviewing the application.

(A) A description of the lake watershed in terms of size, land use (list each major land use classification as a percentage of the whole), and the general topography, including major soil types.

(B) An identification of the major point source pollution discharges in the watershed. If the sources are currently controlled under the National Pollutant Discharge Elimination System (NPDES), include the permit numbers.

(C) An estimate of the percent contribution of total nutrient and sediment loading to the lake by the identified point sources.

(D) An indication of the major nonpoint sources in the watershed. If the sources are being controlled describe the control practice(s), including best land management practices.

(E) An indication of the lake restoration measures anticipated, including watershed management, and a projection of the net improvement in water quality.

(F) A statement of known or anticipated adverse environmental impacts resulting from lake restoration.

(c) Phase 2 applications shall include: (1) The information specified in Appendix A in a diagnostic/feasibility study or its equivalent; (2) certification by the appropriate areawide or State 208 planning agencies that the proposed Phase 2 lake restoration proposal is consistent with any approved 208 planning; and (3) copies of all issued permits or permit applications (including a summary of the status of applications) that are required for the discharge of dredged or fill material under section 404 of the Act.

§ 35.1620-3 Environmental evaluation.

Phase 2 applicants shall submit an evaluation of the environmental impacts of the proposed project in accordance with the requirements in Appendix A of this regulation.

§ 35.1620-4 Public participation.

(a) *General.* (1) In accordance with this Part and Part 25 of this chapter, the applicant shall provide for, encourage, and assist public participation in developing a proposed lake restoration project.

(2) Public consultation may be coordinated with related activities to enhance the economy, the effectiveness, and the timeliness of the effort, or to enhance the clarity of the issue. This procedure shall not discourage the widest possible participation by the public.

(b) *Phase 1.* (1) Phase 1 recipients shall solicit public comment in developing, evaluating, and selecting alternatives; in assessing potential adverse environmental impacts; and in identifying measures to mitigate any adverse impacts that were identified. The recipient shall provide information relevant to these decisions, in fact sheet or summary form, and distribute them to the public at least 30 days before selecting a proposed method of lake restoration. Recipients shall hold a formal or informal meeting with the public after all pertinent information is distributed, but before a lake restoration method is selected. If there is significant public interest in the cooperative agreement activity, an advisory group to study the process shall be formed in accordance with the requirements of § 25.3(d)(4) of this chapter.

(2) A formal public hearing shall be held if the Phase 1 recipient selects a lake restoration method that involves major construction, dredging, or significant modifications to the environment, or if the recipient or the Regional Administrator determines that a hearing would be beneficial.

(c) *Phase 2.* (1) A summary of the recipient's response to all public comments, along with copies of any written comments, shall be prepared and submitted to EPA with a Phase 2 application.

(2) Where a proposed project has not been studied under a Phase 1 cooperative agreement, the applicant for Phase 2 assistance shall provide an opportunity for public consultation with adequate and timely notices before submitting an application to EPA. The public shall be given the opportunity to discuss the proposed project, the alternatives, and any potentially adverse environmental impacts. A public hearing shall be held where the proposed project involves major construction, dredging or other significant modification of the environment. The applicant shall provide a summary of his responses to all public comments and submit the summary, along with copies of any written comments, with the application.

§ 35.1620-5 State work programs and lake priority lists.

(a)(1) A State shall submit to the Regional Administrator as part of its annual work program (§ 35.1513 of this subchapter) a description of the activities it will conduct during the Federal fiscal year to classify its lakes according to trophic condition (§ 35.1630) and to set priorities for implementing clean lakes projects within the State. The work plan must list in priority order the cooperative agreement applications that will be submitted by the State for Phase 1 and Phase 2 projects during the upcoming fiscal year, along with the rationale used to establish project priorities. Each State must also list the cooperative agreement applications, with necessary funding, which it expects to submit in the following fiscal year. This information will assist EPA in targeting resources under § 35.1613.

(2) A State may petition the Regional Administrator by letter to modify the EPA approved priority list established under paragraph (a)(1) of this section. This may be done at any time if the State believes there is sufficient justification to alter the priority list contained in its annual work program, e.g., if a community with a lower priority project has sufficient resources available to provide the required matching funding while a higher priority project does not, or if new data indicates that a lower priority lake will have greater public benefit than a higher priority lake.

(b) Clean lakes restoration priorities should be consistent with the Statewide water quality management strategy (see § 35.1511-2 of this subchapter). In establishing priorities on particular lake restoration projects, States should use as criteria the application review criteria (§ 35.1640-1) that EPA will use in preparing funding recommendations for specific projects. If a State chooses to use different criteria, the State should indicate this to the Regional Administrator as part of the annual work program.

§ 35.1620-6 State and local clearinghouse procedures.

In accordance with § 30.305 of this subchapter, all requirements of OMB Circular A-95 must be met before States submit applications to EPA.

§ 35.1630 State lake classification surveys.

States that wish to participate in the clean lakes program shall establish and submit to EPA by January 1, 1982, a classification, according to trophic condition, of their publicly owned freshwater lakes that are in need of restoration or protection. After December 31, 1981, States that have not complied with this requirement will not be eligible for Federal financial assistance under this subpart until they complete their survey.

§ 35.1640 Application review and evaluation.

EPA will review applications as they are received. EPA may request outside review by appropriate experts to assist with technical evaluation. Funding decisions will be based on the merit of each application in accordance with the application review criteria under § 35.1640-1. EPA will consider Phase 1 applications separately from Phase 2 applications.

§ 35.1640-1 Application review criteria.

(a) When evaluating applications, EPA will consider information supplied by the applicant which address the following criteria:

(1) The technical feasibility of the project, and where appropriate, the estimated improvement in lake water quality.

(2) The anticipated positive changes that the project would produce in the overall lake ecosystem, including the watershed, such as the net reduction in sediment, nutrient, and other pollutant loadings.

(3) The estimated improvement in fish and wildlife habitat and associated beneficial effects on specific fish populations of sport and commercial species.

(4) The extent of anticipated benefits to the public. EPA will consider such factors as (i) the degree, nature and sufficiency of public access to the lake;

(ii) the size and economic structure of the population residing near the lake which would use the improved lake for recreational and other purposes; (iii) the amount and kind of public transportation available for transport of the public to and from the public access points; (iv) whether other relatively clean publicly owned freshwater lakes within 80 kilometer radius already adequately serve the population; and (v) whether the restoration would benefit primarily the owners of private land adjacent to the lake.

(5) The degree to which the project considers the "open space" policies contained in sections 201(f), 201(g), and 208(b)(2)(A) of the Act.

(6) The reasonableness of the proposed costs relative to the proposed work, the likelihood that the project will succeed, and the potential public benefits.

(7) The means for controlling adverse environmental impacts which would result from the proposed restoration of the lake. EPA will give specific attention to the environmental concerns listed in Section (c) of Appendix A.

(8) The State priority ranking for a particular project.

(9) The State's operation and maintenance program to ensure that the pollution control measures and/or in-lake restorative techniques supported under the project will be continued after the project is completed.

(b) For Phase 1 applications, the review criteria presented in paragraph (a) of this section will be modified in relation to the smaller amount of technical information and analysis that is available in the application. Specifically, under criterion (a)(1), EPA will consider a technical assessment of the proposed project approach to meet the requirements stated in Appendix A to this regulation. Under criterion (a)(4), EPA will consider the degree of public access to the lake and the public benefit. Under criterion (a)(7), EPA will consider known or anticipated adverse environmental impacts identified in the application or that EPA can presume will occur. Criterion (a)(9) will not be considered.

§ 35.1650 Award.

(a) Under 40 CFR 30.345, generally 90 days after EPA has received a complete application, the application will either be: (1) Approved for funding in an amount determined to be appropriate for the project; (2) returned to the applicant due to lack of funding; or (3) disapproved. The applicant shall be promptly notified in writing by the EPA Regional Administrator of any funding decisions.

(b) Applications that are disapproved can be submitted as new applications to EPA if the State resolves the issues identified during EPA review.

§ 35.1650-1 Project period.

(a) The project period for Phase 1 projects shall not exceed three years.

(b) The project period for Phase 2 projects shall not exceed four years. Implementation of complex projects and projects incorporating major construction may have longer project periods if approved by the Regional Administrator.

§ 35.1650-2 Limitations on awards.

(a) Before awarding assistance, the Regional Administrator shall determine that:

(1) The applicant has met all of the applicable requirements of § 35.1620 and § 35.1630; and

(2) State programs under section 314 of the Act are part of a State/EPA Agreement which shall be completed before the project is awarded.

(b) Before awarding Phase 2 projects, the Regional Administrator shall further determine that:

(1) When a Phase 1 project was awarded, the final report prepared under Phase 1 is used by the applicant to apply for Phase 2 assistance. The lake restoration plan selected under the Phase 1 project must be implemented under a Phase 2 cooperative agreement.

(2) Pollution control measures in the lake watershed authorized by section 201, included in an approved 208 plan, or required by section 402 of the Act have been completed or are being implemented according to a schedule that is included in an approved plan or discharge permit.

(3) The project does not include costs for controlling point source discharges of pollutants where those sources can be alleviated by permits issued under section 402 of the Act, or by the planning and construction of wastewater treatment facilities under section 201 of the Act.

(4) The State has appropriately considered the "open space" policy presented in sections 201(f), 201(g)(6), and 208(b)(2)(A) of the Act in any wastewater management activities being implemented by them in the lake watershed.

(5)(i) The project does not include costs for harvesting aquatic vegetation, or for chemical treatment to alleviate temporarily the symptoms of eutrophication, or for operating and maintaining lake aeration devices, or for providing similar palliative methods and procedures, unless these procedures are the most energy efficient or cost effective lake restorative method. (ii) Palliative approaches can be supported only where pollution in the lake watershed has been controlled to the greatest practicable extent, and where such methods and procedures are a necessary part of a project during the project period. EPA will determine the eligibility of such a project, based on the applicant's justification for the proposed restoration, the estimated time period for improved lake water quality, and public benefits associated with the restoration.

(6) The project does not include costs for desalinization procedures for naturally saline lakes.

(7) The project does not include costs for purchasing or long term leasing of land used solely to provide public access to a lake.

(8) The project does not include costs resulting from litigation against the recipient by EPA.

(9) The project does not include costs for measures to mitigate adverse environmental impacts that are not identified in the approved project scope of work. (EPA may allow additional costs for mitigation after it has reevaluated the cost-effectiveness of the selected alternative and has approved a request for an increase from the recipient.)

§ 35.1650-3 Conditions on award.

(a) *All awards.* (1) All assistance awarded under the Clean Lakes program is subject to the EPA General Grant conditions (Subpart C and Appendix A of Part 30 of this chapter). (2) For each clean lakes project the State agrees to pay or arrange the payment of the non-Federal share of the project costs.

(b) *Phase 1.* Phase 1 projects are subject to the following conditions:

(1) The recipient must receive EPA project officer approval on any changes to satisfy the requirements of (a)(10) of Appendix A before undertaking any other work under the grant.

(2) (i) Before selecting the best alternative for controlling pollution and improving the lake, as required in paragraph (b)(1) of Appendix A of this regulation, and before undertaking any other work stated under paragraph (b) of Appendix A, the recipient shall submit an interim report to the project officer. The interim report must include a discussion of the various available alternatives and a technical justification for the alternative that the recipient will probably choose. The report must include a summary of the public involvement and the comments that occurred during the development of the alternatives. (ii) The recipient must obtain EPA project officer approval of

the selected alternative before conducting additional work under the project.

(c) *Phase 2.* Phase 2 projects are subject to the following conditions:

(1) (i) The State shall monitor the project to provide data necessary to evaluate the efficiency of the project as jointly agreed to and approved by the EPA project officer. The monitoring program described in paragraph (b)(3) of Appendix A of this regulation as well as any specific measurements that would be necessary to assess specific aspects of the project, must be considered during the development of a monitoring program and schedule. The project recipient shall receive the approval of the EPA project officer for a monitoring program and schedule to satisfy the requirements of Appendix A paragraph (b)(3) before undertaking any other work under the project. (ii) Phase 2 projects shall be monitored for at least one year after construction or pollution control practices are completed.

(2) The State shall manage and maintain the project so that all pollution control measures supported under the project will be continued during the project period at the same level of efficiency as when they were implemented. The State will provide reports regarding project maintenance as required in the cooperative agreement.

(3) The State shall upgrade its water quality standards to reflect a higher water quality use classification if the higher water quality use was achieved as a result of the project (see 40 CFR 35.1550(c)(2)).

(4) If an approved project allows purchases of equipment for lake maintenance, such as weed harvesters, aeration equipment, and laboratory equipment, the State shall maintain and operate the equipment according to an approved lake maintenance plan for a period specified in the cooperative agreement. In no case shall that period be for less than the time it takes to completely amortize the equipment.

(5) If primary adverse environmental impacts result from implementing approved lake restoration or protection procedures, the State shall include measures to mitigate these adverse impacts at part of the work under the project.

(6) If adverse impacts could result to unrecorded archeological sites, the State shall stop work or modify work plans to protect these sites in accordance with the National Historic Preservation Act. (EPA may allow additional costs for ensuring proper protection of unrecorded archeological sites in the project area after reevaluating the cost effectiveness of the procedures and approving a request for a cost increase from the recipient.)

(7) If a project involves construction or dredging that requires a section 404 permit for the discharge of dredged or fill material, the recipient shall obtain the necessary section 404 permits before performing any dredge or fill work.

§ 35.1650-4 Payment.

(a) Under § 30.615 of this chapter, EPA generally will make payments through letter of credit. However, the Regional Administrator may place any recipient on advance payment or on cost reimbursement, as necessary.

(b) Phase 2 projects involving construction of facilities or dredging and filling activities shall be paid by reimbursement.

§ 35.1650-5 Allowable costs.

(a) The State will be paid under § 35.1650-4 for the Federal share of all necessary costs within the scope of the approved project and determined to be allowable under 40 CFR 30.705, the provisions of this subpart, and the cooperative agreement.

(b) Costs for restoring lakes used solely for drinking water supplies are not allowable under the Clean Lakes Program.

§ 35.1650-6 Reports.

(a) States with Phase 1 projects shall submit semi-annual progress reports (original and one copy) to the EPA project officer within 30 days after the end of every other standard quarter. Standard quarters end on March 31, June 30, September 30, and December 31. These reports shall include the following:

(1) Work progress relative to the milestone schedule, and difficulties encountered during the previous six months.

(2) A brief discussion of the project findings appropriate to the work conducted during the previous six months.

(3) A report of expenditures in the past six months and those anticipated in the next six months.

(b) *Phase 2.* States with Phase 2 projects shall submit progress reports (original and one copy) according to the schedule established in the cooperative agreement. The frequency of Phase 2 project progress reports shall be determined by the size and complexity of the project, and shall be required no more frequently than quarterly. The Phase 2 progress report shall contain all of the information required for Phase 1 progress reports indicated in paragraph (a) of this section. This report also must include water quality monitoring data and a discussion of the changes in water quality which appear to have resulted from the lake restoration activities implemented during the reporting period.

(c) *Final Report.* States shall prepare a final report for all grants in accordance with § 30.635-2 of this subchapter. Phase 1 reports shall be organized according to the outline of information requirements stated in Appendix A. All water quality data obtained under the grant shall be submitted in the final report. Phase 2 reports shall conform to the format presented in the EPA manual on "Scientific and Technical Publications," May 14, 1974, as revised or updated. The States shall submit the report within 90 days after the project is completed.

(d) *Financial Status Report.* Within 90 days after the end of each budget period, the grantee shall submit to the Regional Administrator an annual report of all expenditures (Federal and non-Federal) which accrued during the budget period. Beginning in the second quarter of any succeeding budget period, payments may be withheld under § 30.615-3 of this chapter until this report is received.

Appendix A—Requirements for Diagnostic-Feasibility Studies and Environmental Evaluations

Phase 1 clean lakes projects shall include in their scope of work at least the following requirements, preferably in the order presented and under appropriate subheadings. The information required by paragraph (a)(10) and the monitoring procedures stated in paragraph (b)(3) of this Appendix may be modified to conform to specific project requirements to reduce project costs without jeopardizing adequacy of technical information or the integrity of the project. All modifications must be approved by the EPA project officer as specified in §§ 35.1650-3(b)(1) and 35.1650-3(c)(1).

(a) A diagnostic study consisting of:

(1) An identification of the lake to be restored or studied, including the name, the State in which it is located, the location within the State, the general hydrologic relationship to associated upstream and downstream waters and the approved State water quality standards for the lake.

(2) A geological description of the drainage basin including soil types and soil loss to stream courses that are tributary to the lake.

(3) A description of the public access to the lake including the amount and type of public transportation to the access points.

(4) A description of the size and economic structure of the population residing near the lake which would use the improved lake for recreation and other purposes.

(5) A summary of historical lake uses, including recreational uses up to the present time, and how these uses may have changed because of water quality degradation.

(6) An explanation, if a particular segment of the lake user population is or will be more adversely impacted by lake degradation.

(7) A statement regarding the water use of the lake compared to other lakes within a 80 kilometer radius.

(8) An itemized inventory of known point source pollution discharges affecting or which have affected lake water quality over the past 5 years, and the abatement actions for these discharges that have been taken, or are in progress. If corrective action for the pollution sources is contemplated in the future, the time period should be specified.

(9) A description of the land uses in the lake watershed, listing each land use classification as a percentage of the whole and discussing the amount of nonpoint pollutant loading produced by each category.

(10) A discussion and analysis of historical baseline limnological data and one year of current limnological data. The monitoring schedule presented in paragraph (b)(3) of Appendix A must be followed in obtaining the one year of current limnological data. This presentation shall include the present trophic condition of the lake as well as its surface area (hectares), maximum depth (meters), average depth (meters), hydraulic residence time, the area of the watershed draining to the lake (hectares), and the physical, chemical, and biological quality of the lake and important lake tributary waters. Bathymetric maps should be provided. If dredging is expected to be included in the restoration activities, representative bottom sediment core samples shall be collected and analyzed using methods approved by the EPA project officer for phosphorus, nitrogen, heavy metals, other chemicals appropriate to State water quality standards, and persistent synthetic organic chemicals where appropriate. Further, the elutriate must be subjected to test procedures developed by the U.S. Army Corps of Engineers and analyzed for the same constituents. An assessment of the phosphorus (and nitrogen when it is the limiting lake nutrient) inflows and outflows associated with the lake and a hydraulic budget including ground water flow must be included. Vertical temperature and dissolved oxygen data must be included for the lake to determine if the hypolimnion becomes anaerobic and, if so, for how long and over what extent of the bottom. Total and soluble reactive phosphorus (P); and nitrite, nitrate, ammonia and organic nitrogen (N) concentratons must be determined for the lake. Chlorophyll *a* values should be measured for the upper mixing zone. Representative alkalinities should be determined. Algal assay bottle test data or total N to total P ratios should be used to define the growth limiting nutrient. The extent of algal blooms, and the predominant algal genera must be discussed. Algal biomass should be determined through algal genera identification, cell density counts (numbers of cells per milliliter) and converted to cell volume based on factors derived from direct measurements; and reported in biomass of each major genus identified. Secchi disk depth and suspended solids should be measured and reported. The portion of the shoreline and bottom that is impacted by vascular plants (submersed, floating, or emersed higher aquatic vegetation) must be estimated, specifically the lake surface area between 0 and the 10 meter depth contour or twice the Secchi disk transparency depth, whichever is less, and that estimate should include an identification of the predominant species. Where a lake is subject to significant public contact use or is fished for consumptive purposes, monitoring for public health reasons should be part of the monitoring program. Standard bacteriological analyses and fish flesh analyses for organic and heavy metal contamination should be included.

(11) An identification and discussion of the biological resources in the lake, such as fish population, and a discussion of the major known ecological relationships.

(b) A feasibility study consisting of:

(1) An identification and discussion of the alternatives considered for pollution control or lake restoration and an identification and justification of the selected alternative. This should include a discussion of expected water quality improvement, technical feasibility, and estimated costs of each alternative. The discussion of each feasible alternative and the selected lake restoration procedure must include detailed descriptions specifying exactly what activities would be undertaken under each, showing how and where these procedures would be implemented, illustrating the engineering specifications that would be followed including preliminary engineering drawings to show in detail the construction aspects of the project, and presenting a quantitative analysis of the pollution control effectiveness and the lake water quality improvement that is anticipated.

(2) A discussion of the particular benefits expected to result from implementing the project, including new public water uses that may result from the enhanced water quality.

(3) A Phase 2 monitoring program indicating the water quality sampling schedule. A limited monitoring program must be maintained during project implementation, particularly during construction phases or in-lake treatment, to provide sufficient data that will allow the State and the EPA project officer to redirect the project if necessary, to ensure desired objectives are achieved. During pre-project, implementation, and post-project monitoring activities, a single in-lake site should be sampled monthly during the months of September through April and biweekly during May through August. This site must be located in an area that best represents the limnological properties of the lake, preferably the deepest point in the lake. Additional sampling sites may be warranted in cases where lake basin morphometry creates distinctly different hydrologic and limnologic sub-basins; or where major lake tributaries adversely affect lake water quality. The sampling schedule may be shifted according to seasonal differences at various latitudes. The biweekly samples must be scheduled to coincide with the period of elevated biological activity. If possible, a set of samples should be collected immediately following spring turnover of the lake. Samples must be collected between 0800 and 1600 hours of each sampling day unless diel studies are part of the monitoring program. Samples must be collected between one-half meter below the surface and one-half meter off the bottom, and must be collected at intervals of every one and one-half meters, or at six equal depth intervals, whichever number of samples is less. Collection and analyses of all samples must be conducted according to EPA approved methods. All of the samples collected must be analyzed for total and soluble reactive phosphorus; nitrite, nitrate, ammonia, and organic nitrogen; pH; temperature; and dissolved oxygen. Representative alkalinities should be determined. Samples collected in the upper mixing zone must be analyzed for chlorophyll *a*. Algal biomass in the upper mixing zone should be determined through algal genera

identification, cell density counts (number of cells per milliliter) and converted to cell volume based on factors derived from direct measurements; and reported in terms of biomass of each major genera identified. Secchi disk depth and suspended solids must be measured at each sampling period. The surface area of the lake covered by macrophytes between 0 and the 10 meter depth contour or twice the Secchi disk transparency depth, whichever is less, must be reported. The monitoring program for each clean lakes project must include all the required information mentioned above, in addition to any specific measurements that are found to be necessary to assess certain aspects of the project. Based on the information supplied by the Phase 2 project applicant and the technical evaluation of the proposal, a detailed monitoring program for Phase 2 will be established for each approved project and will be a condition of the cooperative agreement. Phase 2 projects will be monitored for at least one year after construction or pollution control practices are completed to evaluate project effectiveness.

(4) A proposed milestone work schedule for completing the project with a proposed budget and a payment schedule that is related to the milestone.

(5) A detailed description of how non-Federal funds will be obtained for the proposed project.

(6) A description of the relationship of the proposed project to pollution control programs such as the section 201 construction grants program, the section 208 areawide wastewater management program, the Department of Agriculture Soil Conservation Service and Agriculture Stabilization and Conservation Service programs, the Department of Housing and Urban Development block grant program, the Department of Interior Heritage Conservation and Recreation Service programs and any other local, State, regional and Federal programs that may be related to the proposed project. Copies of any pertinent correspondence, contracts, grant applications and permits associated with these programs should be provided to the EPA project officer.

(7) A summary of public participation in developing and assessing the proposed project which is in compliance with Part 25 of this chapter. The summary shall describe the matters brought before the public, the measures taken by the reporting agency to meet its responsibilities under Part 25 and related provisions elsewhere in this chapter, the public response, and the agency's response to significant comments. Part 25.8 responsiveness summaries may be used to meet appropriate portions of these requirements to avoid duplication.

(8) A description of the operation and maintenance plan that the State will follow, including the time frame over which this plan will be operated, to ensure that the pollution controls implemented during the project are continued after the project is completed.

(9) Copies of all permits or pending permit applications (including the status of such applications) necessary to satisfy the requirements of section 404 of the Act. If the approved project includes dredging activities or other activities requiring permits, the State must obtain from the U.S. Army Corps of Engineers or other agencies the permits required for the discharge of dredged or fill material under section 404 of the Act or other Federal, State or local requirements. Should additional information be required to obtain these permits, the State shall provide it. Copies of section 404 permit applications and any associated correspondence must be provide to the EPA project officer at the time they are submitted to the U.S. Army Corps of Engineers. After reviewing the 404 permit application, the project officer may provide recommendations for appropriate controls and treatment of supernatant derived from dredged material disposal sites to ensure the maximum effectiveness of lake restoration procedures.

(c) States shall complete and submit an environmental evaluation which considers the questions listed below. In many cases the questions cannot be satisfactorily answered with a mere "Yes" or "No". States are encouraged to address other considerations which they believe apply to their project.

(1) Will the proposed project displace any people?

(2) Will the proposed project deface existing residences or residential areas? What mitigative actions such as landscaping, screening, or buffer zones have been considered? Are they included?

(3) Will the proposed project be likely to lead to a change in established land use patterns, such as increased development pressure near the lake? To what extent and how will this change be controlled through land use planning, zoning, or through other methods?

(4) Will the proposed project adversly affect a significant amount of prime agricultural land or agricultural operations on such land?

(5) Will the proposed project result in a significant adverse effect on parkland, other public land, or lands of recognized scenic value?

(6) Has the State Historical Society or State Historical Preservation Officer been contacted? Has he responded, and if so, what was the nature of that response? Will the proposed project result in a significant adversely effect on lands or structures of historic, architectural, archaeological or cultural value?

(7) Will the proposed project lead to a significant long-range increase in energy demands?

(8) Will the proposed project result in significant and long range adverse changes in ambient air quality or noise levels? Short term?

(9) If the proposed project involves the use of in-lake chemical treatment, what long and short term adverse effects can be expected from that treatment? How will the project recipient mitigate these effects?

(10) Does the proposal contain all the information that EPA requires in order to determine whether the project complies with Executive Order 11988 on floodplains? Is the proposed project located in a floodplain? If so, will the project involve construction of structures in the floodplain? What steps will be taken to reduce the possible effects of flood damage to the project?

(11) If the project involves physically modifying the lake shore or its bed or its watershed, by dredging, for example, what steps will be taken to minimize any immediate and long term adverse effects of such activities? When dredging is employed, where will the dredged material be deposited, what can be expected and what measures will the recipient employ to minimize any significant adverse impacts from its deposition?

(12) Does the project proposal contain all information that EPA requires in order to determine whether the project complies with Executive Order 11990 on wetlands? Will the proposed project have a significant adverse effect on fish and wildlife, or on wetlands or any other wildife habitat, especially those of endangered species? How significant is this impact in relation to the local or regional critical habitat needs? Have actions to mitigate habitat destruction been incorporated into the project? Has the recipient properly consulted with appropriate State and Federal fish, game and wildlife agencies and with the U.S. Fish and Wildlife Service? What were their replies?

(13) Describe any feasible alternatives, to the proposed project in terms of environmental impacts, commitment of resources, public interest and costs and why they were not proposed.

(14) Describe other measures not discussed previously that are necessary to mitigate adverse enivironmental impacts resulting from the implementation of the proposed project.

APPENDIX H - REVIEW COMMENTS RECEIVED ON THE DRAFT FINAL REPORT

STATE of INDIANA

STATE BOARD OF HEALTH

AN EQUAL OPPORTUNITY EMPLOYER

INDIANAPOLIS

Address Reply to:
Indiana State Board of Health
1330 West Michigan Street
P. O. Box 1964
Indianapolis, IN 46206-1964

March 17, 1983

William W. Jones, Project Manager
School of Public and Environmental Affairs
Environmental Systems Application Center
400 East Seventh Street
Bloomington, IN 47405

Dear Mr. Jones:

Re: Staff Review of the Draft
Cedar Lake Restoration Feasibility
Study-Final Report

Staff has reviewed the referenced report and found it to be complete and well thought out. However, all reviewers were of the opinion that regulating boat speed and prohibiting live bait (minnow) fishing would be very difficult if not impossible.

Although it is recognized that the costs are extremely high, it is the consensus of our biologists that dredging to remove some of the floculent organic detritus from the lake would be beneficial if it could be accomplished. This does not mean, however, that we will not support the project if dredging is not included. If the alum treatment and biomanipulation can be made to work here, it should be a model for similar projects in other portions of the country.

Under product modification on pages 137 and 138, it should be pointed out that Indiana has had a phosphorus detergent ban since 1971. The present phosphorus limit of 0.5% P by weight in household detergents has been in effect since 1973. A reduction of about 60% of the phosphorus concentration of sewage was achieved as a result.

Very truly yours,

John L. Winters

John L. Winters, Chief
Water Quality Surveillance
and Standards Branch
Division of Water Pollution Control

JLW/jad

STATE of INDIANA

INDIANAPOLIS, 46204

DEPARTMENT OF NATURAL RESOURCES

JAMES M. RIDENOUR
DIRECTOR

Bob Robertson
Bass Lake State Fish Hatchery
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Knox, Indiana 46534

July 8, 1983

Dr. William Jones
Environmental Systems Application Center
School of Public and Environmental Affairs
Indiana University
Bloomington, Indiana

Dear Dr. Jones,

I have discussed your proposed project for Cedar Lake with our Regional Supervisor Gary Hudson (TriLakes Fishery Station, Columbia City, IN 46725). Gary and I both agree that we would like to see an improvement in the fishery population of Cedar Lake. The lake renovation conducted by our division in 1966 produced only a temporary improvement in sport fishing. We believe a major factor in the limited success of that renovation was a continuing problem with water quality. Our 1977 lake survey report recommended the following:

1. The Department of Natural Resources should advise local residents how to modify the two dams at Lake Dalecarlia in order to prevent further rough fish contamination.

2. All local businesses and residences should immediately hook up to the municipal sewage system.

3. Channel catfish should be supplementally stocked into Cedar Lake.

4. If the above improvements are made and the fishery remains unsatisfactory, a total renovation should be considered provided that the water quality has improved sufficiently for bass and bluegill management.

It appears that although water quality has improved somewhat, the quality of the fishery is still poor. If sufficient federal funds become available as a result of the feasibility study, the division of Fish & Wildlife would be interested in exploring the possibility of another renovation.

The cost of another Cedar Lake renovation, including modification of the Lake Dale Dams, is almost prohibitive for our division alone to pay. Hopefully with the assistance of federal funding, such a renovation project could become a reality. Providing a quality fishery in such a populated portion of our state would have immense benefits.

Sincerely,

Bob Robertson
Fishery Biologist

UNIVERSITY OF MINNESOTA
TWIN CITIES

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March 11, 1983

William W. Jones
Environmental Systems Application Center
School of Public and Environmental Affairs
Indiana University
Bloomington, Indiana 47405

Dear Bill,

Just a short note to tell you that I enjoyed reading your draft on Cedar Lake and in general agree with what you are planning to do. One caution I would have is that the fish restocking program be done carefully. We restocked Round Lake with Bluegill and bass and it looks as though the bluegill may be getting away from the bass and reducing the sizes and numbers of the large <u>Daphnia</u>. I would suggest discussing with your DNR people the possibility of using a forage fish that is more readily eaten by bass and/or walleye.

Best regards,

Joseph Shapiro
Professor

JS:rmf

APPENDIX I - ENVIRONMENTAL EVALUATION

Appendix A of the final regulation establishing operating rules and procedures for the Clean Lakes Program includes a fourteen question environmental evaluation which must be completed before a Section 314 grant can be awarded (see Appendix G). The questions are presented here along with our responses.

1. "Will the proposed project result in the displacement of any people?"

   It is not anticipated that any people will have to be moved as a result of this project.

2. "Will the proposed project deface existing residences or residential areas? What mitigative actions such as landscaping, screening, or buffer zones have been considered? Are they included?"

   No residences or residential areas will be defaced as a result of this project. Construction activity at the outlet structure at Cedar Creek may involve digging and the temporary parking of construction vehicles in that vicinity. If liquid alum is applied to Cedar Lake, a railroad tank car will likely be used to deliver the chemical and will require an area for unloading during the approximately two weeks it will take to apply the chemical.

3. "Will the proposed project be likely to lead to a change in established land use patterns, such as increased development pressure near the lake? To what extent and how will this change be controlled through land use planning, zoning, or through other methods?"

   Any improvement in the water quality of Cedar Lake may create increased use of the lake for recreational purposes. Increased development along the lakeshore is unlikely since development is presently near saturation in this area. A zoning ordinance for Cedar Lake was recently adopted in 1980. The lead state agency involved in the eventual restoration of Cedar Lake should coordinate plans with the Cedar Lake Plan Commission.

4. "Will the proposed project adversely affect a significant amount of prime agricultural land or agricultural operations on such land?"

   No agricultural land will be affected by the proposed project.

5. "Will the proposed project result in a significant adverse effect on parkland, other public land, or lands of recognized scenic value?"

No significant impacts are anticipated on parkland, other public land, or lands of recognized scenic value as a result of this project. Some increased use of local parklands could occur if an improved Cedar Lake attracts a larger user population.

6. "Has the State Historical Society or State Historical Preservation Officer been contacted by the grantee? Has he responded, and if so, what was the nature of that response? Will the proposed project result in a significant adverse effect on lands or structures of historic, architectual, archaeological, or cultural value?"

   The State Historical Society Historical Preservation Officer has not been contacted in this study. It is not anticipated that any land or structures of historic, architectual, archaeological, or cultural value need be adversely affected by this project.

7. "Will the proposed project lead to a significant long-range increase in energy demands?"

   It is not anticipated that the project will lead to any increases in energy demand, unless a cleaner Cedar Lake will attract tourists from greater distances. This could possibly lead to greater consumption of automobile fuels.

8. "Will the proposed project result in significant and long range adverse changes in ambient air quality or noise levels? Short term?"

   No significant long term or short term changes in ambient air quality or noise levels are expected to result from the project.

9. "If the proposed project involves the use of in-lake chemical treatment, what long and short term adverse effects can be expected from that treatment? How will the project recipient mitigate these effects?"

   The use of chemical precipitants, such as aluminum sulfate, may be useful for removal of nutrients in conjunction with a recommended restoration plan. Short term reduction in water transparency will result as the aluminum floc forms and settles to the lake bottom. This will be greatly reduced by hypolimnetic application of the alum. High winds or motor boats could disrupt the floc barrier and resuspend the floc material if turbulence from these sources reached the lake bottom. This potential effect will be greatly minimized by applying the alum only in deeper water areas below 2.5 m (8 ft.), where the flocculent silty clay sediments lie.

Toxic effects from aluminium release will be avoided by maintaining a pH level of 6 or greater during and after alum application. At these pH levels, aluminum remains bound to phosphorus or hydroxide ions and does not go into solution.

10. "Does the proposal contain all the information that EPA requires in order to determine whether the project complies with Executive Order 11988? Is the proposed project located in a floodplain? If so, will the project involve construction of structures in the floodplain? What steps will be taken to reduce the possible effects of flood damage to the project?"

Modification of the outlet structure on Cedar Creek is proposed to prevent rough fish from entering Cedar Lake from Cedar Creek. Deepening the plunge pool on the downstream side of the dam or installing a fish barrier on the existing dam would involve construction in the floodplain of Cedar Creek and therefore would require the appropriate permit(s) from the Indiana Department of Natural Resources. Plans for such modifications would be developed in conjunction with the Indiana DNR using appropriate technologies and safeguards.

11. "If the project involves physically modifying the lake shore or its bed or its watershed, by dredging, for example, what steps will be taken to minimize any immediate and long term adverse effects of such activities? When dredging is employed, where will the dredged materials be deposited, what can be expected and what measures will the grantee employ to minimize any significant adverse impacts from its deposition?"

Dredging and disposal plans are discussed in Section 6.3 of this report. However, since dredging was not determined to be technologically feasible for improving Cedar Lake, it is not being recommended.

12. "Does the proposed project proposal contain all information that EPA requires in order to determine whether the project complies with Executive Order 11990 on wetlands? Will the proposed project have a significant adverse effect on fish and wildlife, or on wetlands or any other wildlife habitat, especially those of endangered species? How significant is this impact in relation to the local or regional critical habitat needs? Have actions to mitigate habitat destruction been incorporated into the project? Has the recipient properly consulted with appropriate State and Federal Fish, game and wildlife agencies and with the U.S. Fish and Wildlife Service? What were their replies?"

Recommendations from this study strive to protect wetlands adjacent to Cedar Lake from any degradation. No construction activities are proposed that will affect these wetlands. No endangered species are known to occur in Cedar Lake Marsh or the lake itself. However, a fisheries renovation of Cedar Lake will include treating both Cedar Lake Marsh and the north wetland with rotenone or a similar poison. Fisheries specialists with the Indiana DNR have been consulted and they will conduct the renovation if it is implemented.

13. "Describe any feasible alternatives to the proposed project in terms of environment impacts, commitment of resources, public interest and costs and why they were not proposed.

The environmental impacts, costs, public interest, and resource requirements of all feasible alternatives are described in Chapter 6 of this report.

14. "Describe other measures not discussed previously that are necessary to mitigate adverse environmental impacts resulting from the implementation of the proposed project."

Measures designed to mitigate adverse environmental impacts resulting from this project are described in Chapter 6.